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13. ABSTRACT *(Maximum 200 words)*
This report describes the feature calibration and alignment (FCA) methodology and the results of applying FCA to the Navy's COAMPS mesoscale weather forecast system. FCA quantifies different components of error by defining horizontal adjustment fields of displacements and amplifications to be applied to the forecast fields. The adjustment is determined by minimizing an objective function which constrains the distorted forecast field to closely fit the available observations, and ensures that the final adjustment produced by the minimization is relatively smooth and not too large. The methodology was applied to short-term (12-hour) COAMPS model forecasts, which were compared against SSM/I retrievals of integrated water vapor (IWV). The adjusted forecasts were then used as the first guess fields of the COAMPS optimal interpolation data analysis cycle. Results from three case studies of marine storms over the North Pacific indicate that the adjustments to the first guess led to an improvement of the IWV forecasts. They also indicate that the adjustments are diminished during the data analysis steps of the COAMPS data assimilation system and during the first 12 hours of the forecast, suggesting the need for more effective ways of initializing the COAMPS model with the adjusted fields.

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Final Report [1]

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Techniques to Assimilate SSM/I Observations of Marine Atmospheric Storms

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December 11, 1998[4]

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1 Executive Summary

This report describes the feature calibration and alignment (FCA) methodology and the results of applying FCA to the Navy's COAMPS mesocale weather forecast system. FCA analyzes the difference between two meteorological fields in terms of displacement differences, bias or amplitude differences and residual differences. The FCA paradigm mimics that of a synoptic meteorologist by describing forecast errors as phase errors, intensification errors, etc. FCA quantifies these different components of error by defining horizontal adjustment fields of displacements and amplifications to be applied to the forecast fields. The adjustment is determined by minimizing an objective function which constrains the distorted forecast field to closely fit the available observations, and ensures that the final adjustment produced by the minimization is relatively smooth and not too large.

The methodology was applied to short-term (12 h) COAMPS model forecasts, which were compared against SSM/I retrievals of integrated water vapor (IWV). The adjusted forecasts were then used as the first guess fields of the COAMPS optimal interpolation data analysis cycle. Several case studies of marine storms over the North Pacific were identified: each presented clearly visible signatures in the IWV data, and interesting synoptic situations representing significant forecast challenges. Of these, three were studied in detail.

The results indicate that the adjustments to the first guess lead to an improvement of the IWV forecasts. They also indicate that the adjustments only partially survive the data analysis steps of the COAMPS data assimilation system, greatly diminishing its potential impact. More effective ways of initializing the COAMPS model with the adjusted model fields are required, since the impact diminishes during the first 12 hours of the forecast.

2 Introduction and motivation

Marine atmospheric storms affect the ability of the Navy, Coast Guard, and commercial marine interests to operate [1]. Additionally, many population centers are located near coastal areas and can be directly affected by such storms.

The sparsity of conventional observations over oceanic regions makes it imperative that all other available data sources, in particular satellite data from polar and geostationary platforms be used to the maximum extent possible. The use of such data in numerical analyses and forecasts is currently limited. One reason for this underutilization is the unconventional nature of many remote sensing systems. For example, the DMSP SSM/I observes integrated water vapor (IWV), but the forecast model, and therefore the analysis system, requires humidity on a vertical grid. Another problem is that data assimilation systems tend to reject moisture information and information concerning the surface wind [7, 5].

The SSM/I data have great potential for monitoring and depicting marine storms and related synoptic features. To attain this potential we proposed a novel technique for assimilating SSM/I observations. In plain terms, we match the observable features, shifting the short term forecast (or background) of the data assimilation system to best match the available satellite data. Our approach to this problem is technically, a novel characterization

of errors for numerical weather predictions. The basic idea is to characterize forecast errors as an adjustment, composed of continuous displacement and amplification fields.

We have applied these concepts to SSM/I observations of integrated water vapor (IWV) in a previous study [6] (hereafter HG96) supported by Navy contract N00014-95-C-0100. This work demonstrates that these data are ideal for pinpointing the location and structure of marine storms. For HG96 we prototyped and performed initial testing of algorithms for a variational analysis method to make use of these data for initializing numerical forecasts of these storms. In the present study this algorithm is applied to several cases of marine storms off the California coast, using the Navy's COAMPS forecast model and data assimilation system. The data and COAMPS model data are described in detail in Section 3, the methodology used for assimilation of the SSM/I data in Section 4, and results are presented in Section 5.

3 Case Study Data

3.1 COAMPS model data

All case studies described used integrations of the Navy's COAMPS mesoscale model [4] in the following configuration. The model was run using an outer grid of 61 × 61 gridpoints, with a gridpoint spacing of 81 km on a Lambert conformal projection. The horizontal area (see Fig. 1) extends from the California coast westward to Hawaii, and includes parts of the Western United States. A total of 30 layers in the vertical were used, 11 of which are below 2 km (see Table 1). The COAMPS model σ is a terrain-following height coordinate defined by $\sigma = (z - z_s)z_t/(z_t - z_s)$, where z_t is the height of the top of the domain, and z_s is the model terrain; over the ocean, σ is equivalent to height.

Table 1: COAMPS model σ-levels

Level	1	2	3	4	5	6	7	8
σ (m)	31,050	24,400	19,400	16,050	14,300	13,300	12,425	11,675

Level	9	10	11	12	13	14	15	16
σ (m)	10,925	10,175	9,425	8,675	7,800	6,800	5,800	4,800

Level	17	18	19	20	21	22	23	24
σ (m)	3,900	3,100	2,300	1,600	1,100	750	500	330

Level	25	26	27	28	29	30		
σ (m)	215	140	90	55	30	10		

3.2 SSM/I data

The SSM/I retrievals of integrated water vapor are used. The data are thinned (only every sixth observation is kept) before their use in the COAMPS OI. The operational database was used by the OI in all cases. In the experiments described below, the SSM/I IWV observations used in the Navy's COAMPS OI were also used to determine the FCA adjustment for the first case study (19 March 1997). SSM/I data obtained from Remote Sensing Systems (www.ssmi.com) were used for this purpose for the two remaining case studies (13 February 1997 and 15 January 1998). Approximately every tenth observation from this 0.25 by 0.25 degree resolution dataset was used.

Retrievals of instantaneous rain rate from SSM/I data were also obtained from Remote Sensing Systems for the purpose of verifying the model forecasts of precipitation.

4 Methodology

4.1 Control Runs

For comparison purposes, control forecasts were generated using the model initialization procedure usually followed for the COAMPS model. The COAMPS forecasts were initialized using the COAMPS Optimum Interpolation (OI) data assimilation scheme. For the cases described here, the first guess field used in the OI consists of a 12 h forecast from a large-scale analysis from the Navy's NOGAPS data assimilation system. The OI is performed on the mandatory pressure levels (1000, 925, 850, 700, 500, 400, 300, 250, 200, 150, 100, 70, 50, 30, 20, and 10 hPa). The model's first guess is interpolated from the model's σ-levels to the pressure levels before the analysis, and the analysis increments are interpolated back to the model's vertical levels before the beginning of the forecast. The SSM/I IWV observations are used in the analysis to adjust the profile of the first guess humidity field.

4.2 Adjustment of the first guess

The first guess IWV field (computed from the model vapor pressure values at the model's σ-levels) is adjusted for a better fit with the available SSM/I observation over the model domain. Formally, we minimize the following objective function:

$$J = J_r + J_d + J_o + J_a,$$

by varying the displacement and amplification fields. The residual cost function, J_r, measures the misfit of the adjusted first guess to the SSM/I data. Minimizing J_r improves the agreement between the (adjusted) first guess and the SSM/I data. The additional penalty terms in the objective function, J_d, J_o, and J_a, ensure that the final adjustment produced by the minimization is relatively smooth and not too large. The smoothness penalty function, J_d measures the roughness of the x- and y-displacements and the amplification, ensuring

that the adjustment is large scale; the term J_o measures the mean square size of the adjustment, which tends to suppress adjustments in data-void areas. Finally, the barrier penalty function, J_a, measures the magnitude of the adjustment components in a way so that small adjustments are not penalized, but large adjustments are penalized heavily. This has the effect of setting up a barrier to the size of the adjustments which are determined. These last three terms are evaluated using the spectral coefficients of the adjustment.

Mathematical details of the objective function computation are given in HG96. The algorithm used here differs from that description in two respects: (1) the additional term J_o is included here, computed in the exact same way as J_d except that the mean square value of the adjustments is used instead of the mean square Laplacian, and (2) a different coordinate system and spectral basis functions are used here. Horizontal positions are computed in terms of grid coordinates on the outermost COAMPS grid ($x \in [1, N_x]$, $y \in [1, N_y]$). The basis functions b_k vanish at the grid boundaries,

$$b_k = 2\sin(m_k x')\sin(n_k y') \; .$$

For convenience we have defined scaled coordinates, $x' = \pi(x-1)/(N_x-1)$ and $y' = \pi(y-1)/(N_y-1)$, so that $(x', y') \in [0, \pi]$. All wavenumbers m_k and n_k with total wavenumber not exceeding some truncation wavenumber N $(\sqrt{m_k^2 + n_k^2} \leq N)$ are included in the representation.

To minimize J we use the built-in Splus function `nlminb`, which implements the algorithms of Gay [2, 3] and which uses function values and gradients of J. The gradient of J with respect to the control vector variables is computed using the adjoint of the objective function calculation.

After J is minimized, the resulting horizontal fields of displacements and amplifications are then used to adjust the three-dimensional first guess fields of all variables. Since the adjustments are a single horizontal field, their vertical distribution must be specified. The most straightforward distribution is a constant adjustment, and this was used here. The adjustments were applied to the first guess fields on the mandatory pressure levels before their use in the pressure-level analysis, and to the first guess field on σ-levels. For consistency with the adjustment of the vertically integrated moisture used in the optimization procedure, both the amplification and the displacements are applied to the vapor pressure field on the mandatory pressure levels, and the corresponding σ-level moisture variable. The displacements only are applied to the height, temperature, and wind fields. Since SSM/I observations are only available over water, no adjustments are performed over land and along a coastal buffer zone of 4 gridpoints (approximately 240 km), and adjustments are reduced in magnitude an additional 4 gridpoints from this buffer zone.

5 Results

5.1 19 March 1997

5.1.1 Case Description

The synoptic situation at the beginning of the 24 h forecast (12 UTC 19 March) was dominated by a mature marine low-pressure system located in the northwest quadrant of the model domain, with an associated cold front extending southwestward from the California coast. A pronounced tongue of moisture exists just ahead of this front, as discussed in more detail below. At 500 hPa, a cut-off low lies above the surface low, and a trough extends in a southerly direction, well to the west of the surface front. Throughout the ensuing 24 h control forecast, the surface low weakens and slowly moves eastward;the surface cold-front also progresses eastward, while an anticyclone develops in its wake. At 500 hPa, this is accompanied by a rapid eastward progression of the trough.

5.1.2 First Guess Adjustment and analysis and forecast impacts

A 12 h COAMPS forecast valid at 12 UTC 19 March 1997 was used as the first guess field in this case. As can be seen in Figure 1, the SSM/I data, which covers part of the moist tongue evident in the first guess IWV, indicates that the moisture tongue is too far to the west in the first guess. The adjustment algorithm was applied to this data with a number of different settings for the adjustable parameters that control the smoothness, barrier, and absolute magnitude constraints (J_d, J_a, and J_o). Based upon a subjective evaluation of the results, the following set of parameters was chosen. The smoothness factor ν=1 affects the amount of smoothing by controlling the contributions by higher wavenumbers to the smoothness penalty function. The amplitude factor $m = 0.1$ provides a flexible contraint on the spectral coefficients of the adjustment and is contained in the weighting of the barrier penalty function. The amplitude factor $n = 10$ controls the steepness of the barrier function. The displacement vectors and amplification factors for this choice (also shown in Figure 1) act to correct this first guess error through a combination of displacements and amplifications; in this case, however, the amplification has only a small effect (results are not appreciably different if only displacements are allowed for the adjustment). Adjustments are generally small in areas not covered by SSM/I data.

Five separate forecasts (Table 2) were generated from the initial data at 12 UTC 19 March: a control forecast (Run b), which used the unadjusted first guess field in the COAMPS data assimilation scheme, and an adjusted case (Run d), in which the adjustments were applied to all pressure level data. An analogous set of control (Run a) and adjusted (Run c) forecast runs were performed in which no data was supplied to the data assimilation system. Finally, the effect of only allowing displacements and no amplifications in the adjustment step was tested in Run e.

In the nominal case (Runs b and d), the first guess (Figure 2) is further modified in the analysis step (Figure 3), which diminishes the differences between the control and adjusted

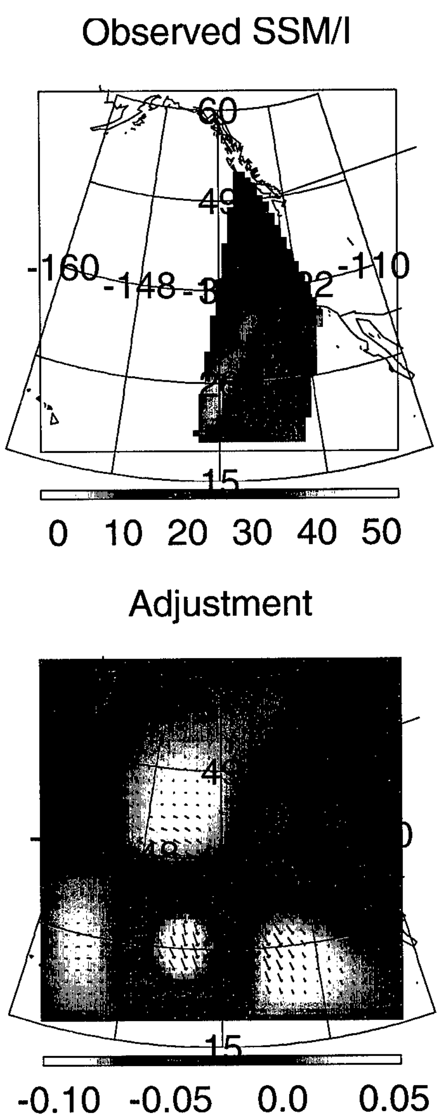

Figure 1: FCA for 12 UTC 19 March 1997. The SSM/I observations are shown in the top left panel; the adjusted first guess in the top right panel; the adjustment amplification factors and displacement vectors in the bottom left panel; and the original first guess integrated water vapor field in the bottom right panel.

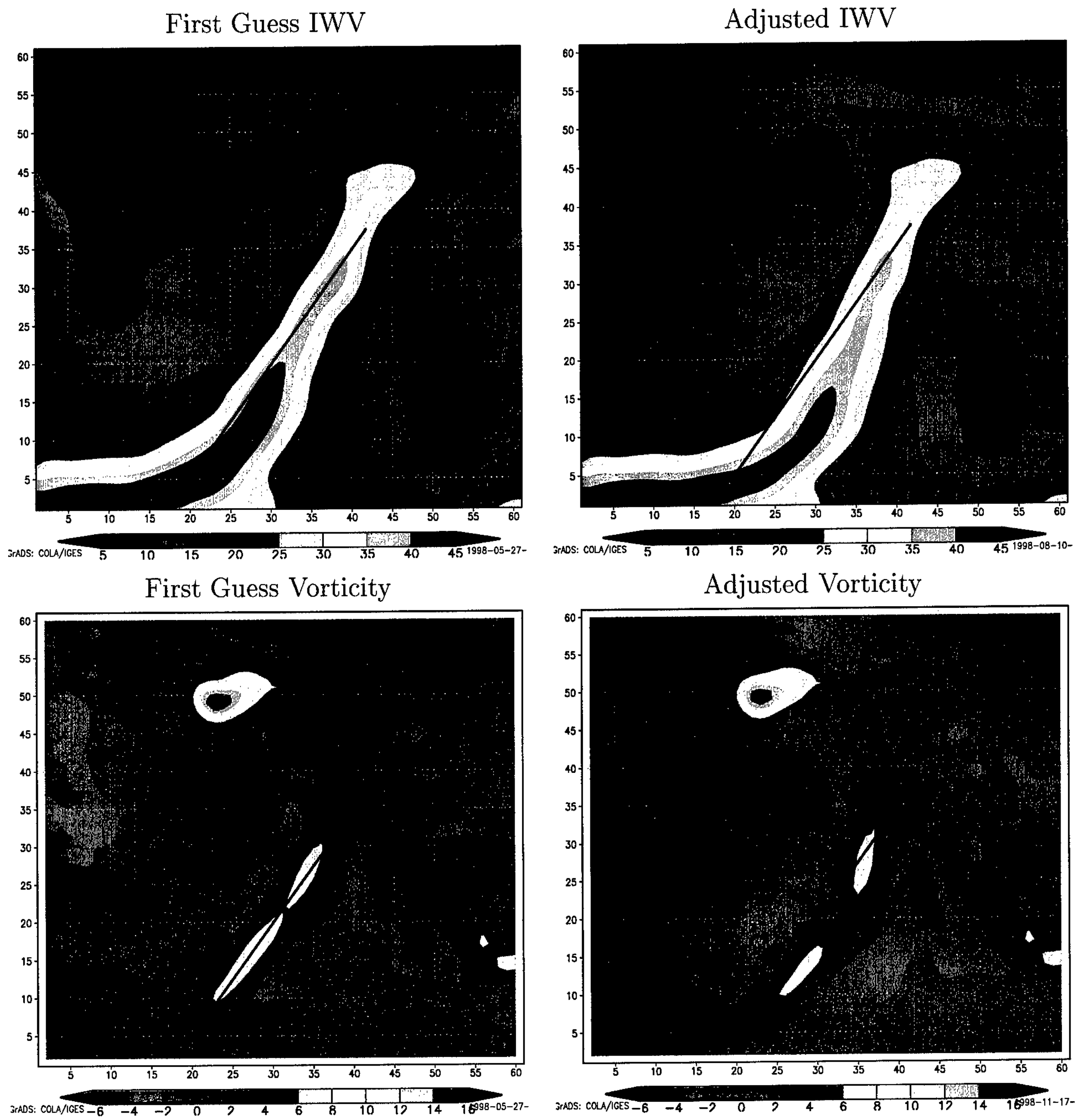

Figure 2: First guess IWV and 1000 hPa relative vorticity for 12 UTC 19 March 1997. Shown are the control first guess fields (Runs a and b, left column) of integrated water vapor (IWV, in $kg\,m^{-2}$) and 1000 hPa relative vorticity ($10^{-5}s^{-1}$), and the corresponding adjusted fields (Runs c and d, right column). The straight line indicates the position of the surface front in the first guess (as indicated by the 1000 hPa relative vorticity maximum).

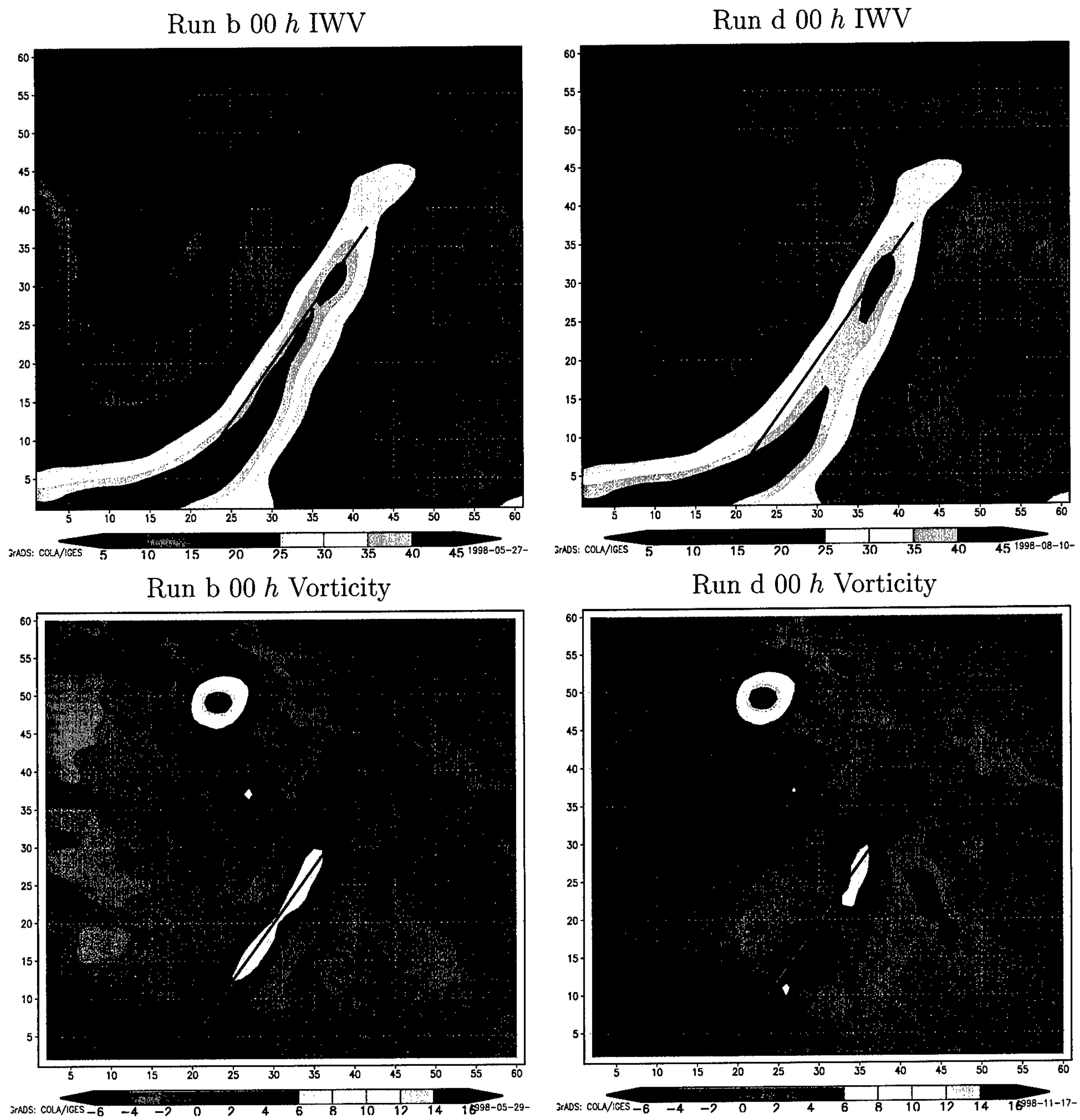

Figure 3: Analysis IWV and 1000 hPa relative vorticity for 12 UTC 19 March 1997. Shown are the control analysis fields (Run b, left column) of integrated water vapor (IWV, in $kg\,m^{-2}$) and 1000 hPa relative vorticity ($10^{-5}s^{-1}$), and the corresponding fields from the adjusted run (Run d, right column). The straight line indicates the position of the surface front in the first guess (as indicated by the 1000 hPa relative vorticity maximum).

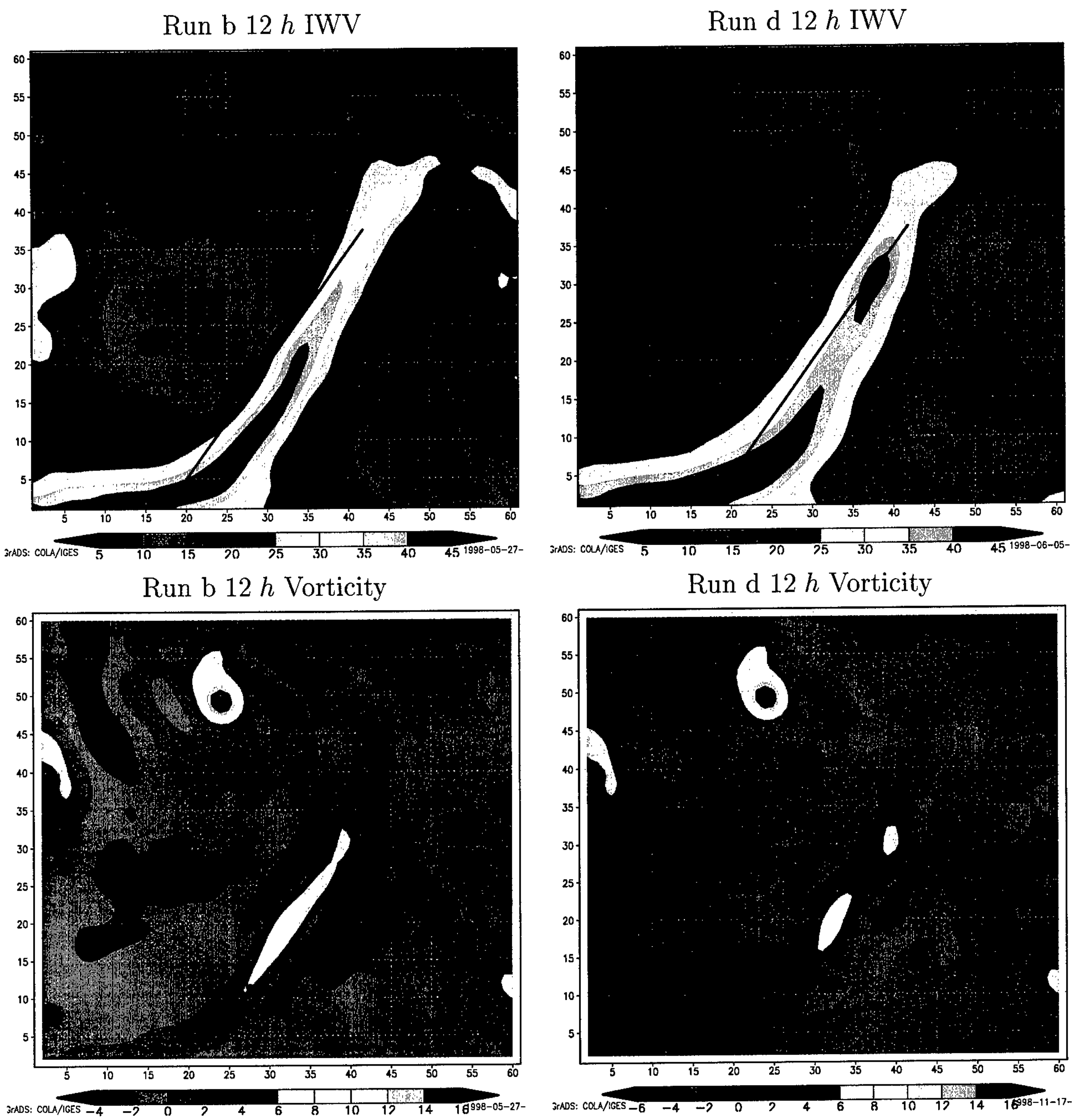

Figure 4: The 12 h forecast IWV and 1000 hPa relative vorticity valid 00 UTC 20 March 1997. Shown are the control fields (Run b) of integrated water vapor (IWV, in $kg\,m^{-2}$) and 1000 hPa relative vorticity ($10^{-5}s^{-1}$), and the corresponding fields from the adjusted case (Run d). The straight line indicates the position of the surface front in the first guess, as before.

Description	Run	Adjustment		Analysis
		Amplification	Displacements	
No Data Control	a	No	No	No
Nominal Control	b	No	No	Yes
No Data FCA	c	Yes	Yes	No
Nominal FCA	d	Yes	Yes	Yes
Displacements only FCA	e	No	Yes	Yes

Table 2: Experiments for 19 March 1997.

initial state. Figure 4 shows the 12 h forecast fields of IWV and vorticity for the nominal control (Run b, left column) and adjusted (Run d, right column) forecasts. There are still some differences in the IWV fields, but they are much smaller than those of the first guess, both because of the analysis and the forecast. The position of the wind-shift line is also no longer visibly different in the two forecasts. However, the front is less organized and weaker in the adjusted (Run d) case.

For this case, the amplification has only a small effect: the adjusted first guess and resulting forecasts for Run e (without amplification adjustments) are not appreciably different from those of Run d (with amplification adjustments).

The 12 h forecasts of the "nodata" runs (Runs a and c, Figure 5) show somewhat larger differences between control and adjusted than in the nominal case: the IWV in the moisture tongue is lower in the adjusted run, and the vorticity maximum along the front is weaker, as well. However, the position of the front is also no longer distinguishable in the two runs.

Verification of the 12 h IWV forecasts against SSM/I observations available at that time (Table 3) show that the adjustments have a small, but positive impact in terms of mean square statistics, although there is a concomitant increase in the positive bias. The improvement is greatest for the nodata run (Run c), smaller for the nominal run (Run d), and smallest when only displacements were used in the adjustment (Run e). By comparison, the nominal error of the SSM/I IWV retrievals is approximately 1 kg/m^2, which is larger than any of the differences except for the improvement in the nodata case.

Comparison of the precipitation fields in the different runs show the effects of the adjustments more clearly than in some of the other fields. The main difference between the adjusted and control runs are in the position and strength of the precipitation along the cold front. At the beginning of the forecast (Figure 6), the precipitation is displaced along with the other fields, but also weakened. As the forecast progresses (Figures 7 and 8), this precipitation weakens further in the adjusted run, whereas it gains in strength in the control run. The 6 h accumulated precipitation shows the effect of both the positional shift and weakening for the first 6 hours, but essentially only a weakening for the second 6 hour period. Comparison of 1-hourly precipitation against the instantaneous precipitation rates observed by the SSM/I (Table 4), however, shows only very small differences, although there is a suggestion that the adjusted runs tend to underpredict precipitation. All these differences are smaller than the typical SSM/I rain rate errors [8].

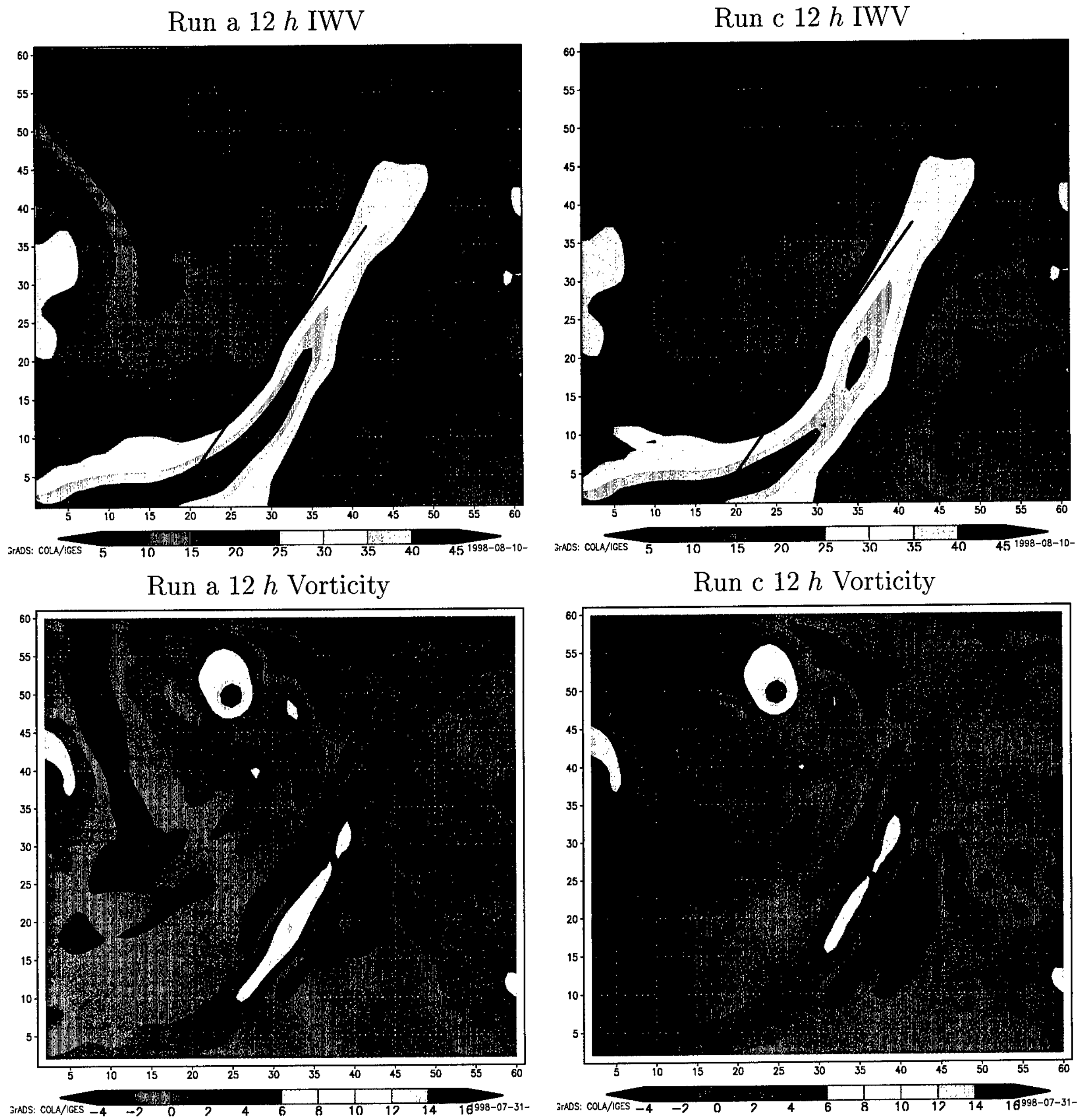

Figure 5: The 12 h forecast IWV and 1000 hPa relative vorticity for the "nodata" runs valid 00 UTC 20 March 1997. Shown are the control fields (Run a, left column) of integrated water vapor (IWV, in $kg\,m^{-2}$) and 1000 hPa relative vorticity ($10^{-5}s^{-1}$), and the corresponding fields from the adjusted case (Run c, right column). The straight line indicates the position of the surface front in the first guess, as before.

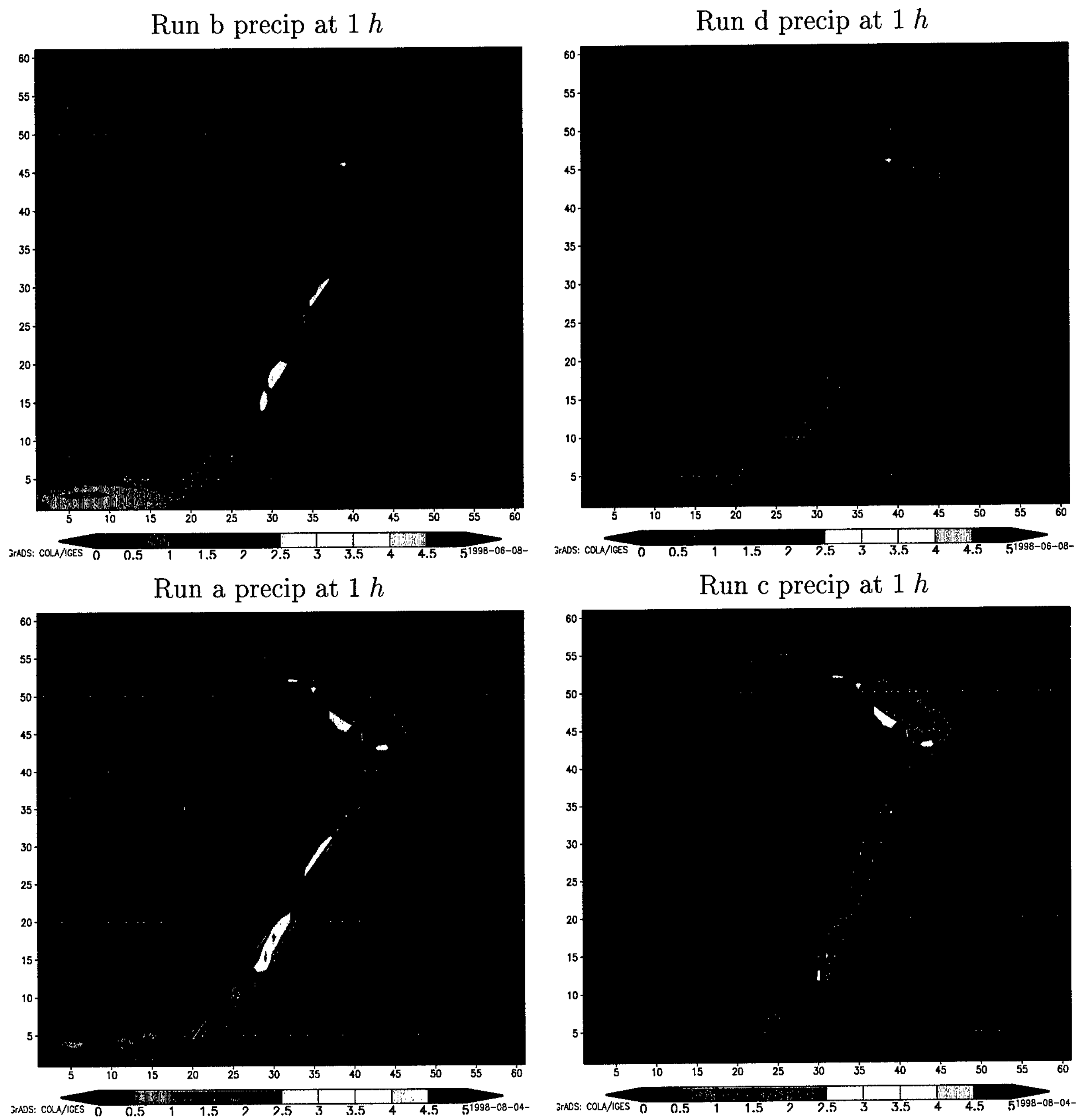

Figure 6: Forecast 1 h accumulated precipitation valid at 13 UTC 19 March 1979. Shown are the nominal (top row) and nodata (bottom row) forecasts, without (left column) and with (right column) adjustments. The straight line indicates the position of the surface front in the first guess.

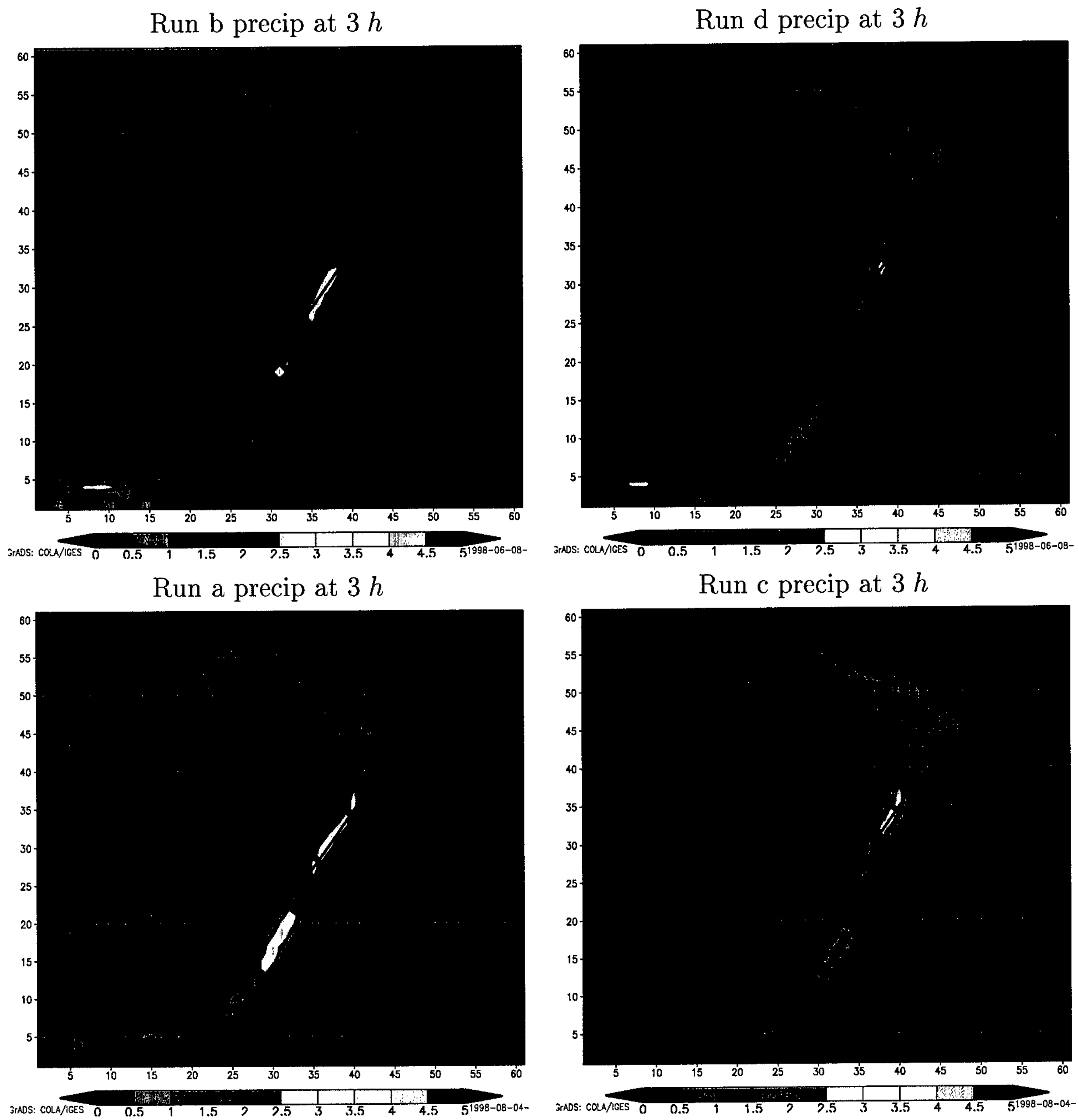

Figure 7: Forecast 1 h accumulated precipitation valid at 15 UTC 19 March 1979. Shown are the nominal (top row) and nodata (bottom row) forecasts, without (left column) and with (right column) adjustments. The straight line indicates the position of the surface front in the first guess.

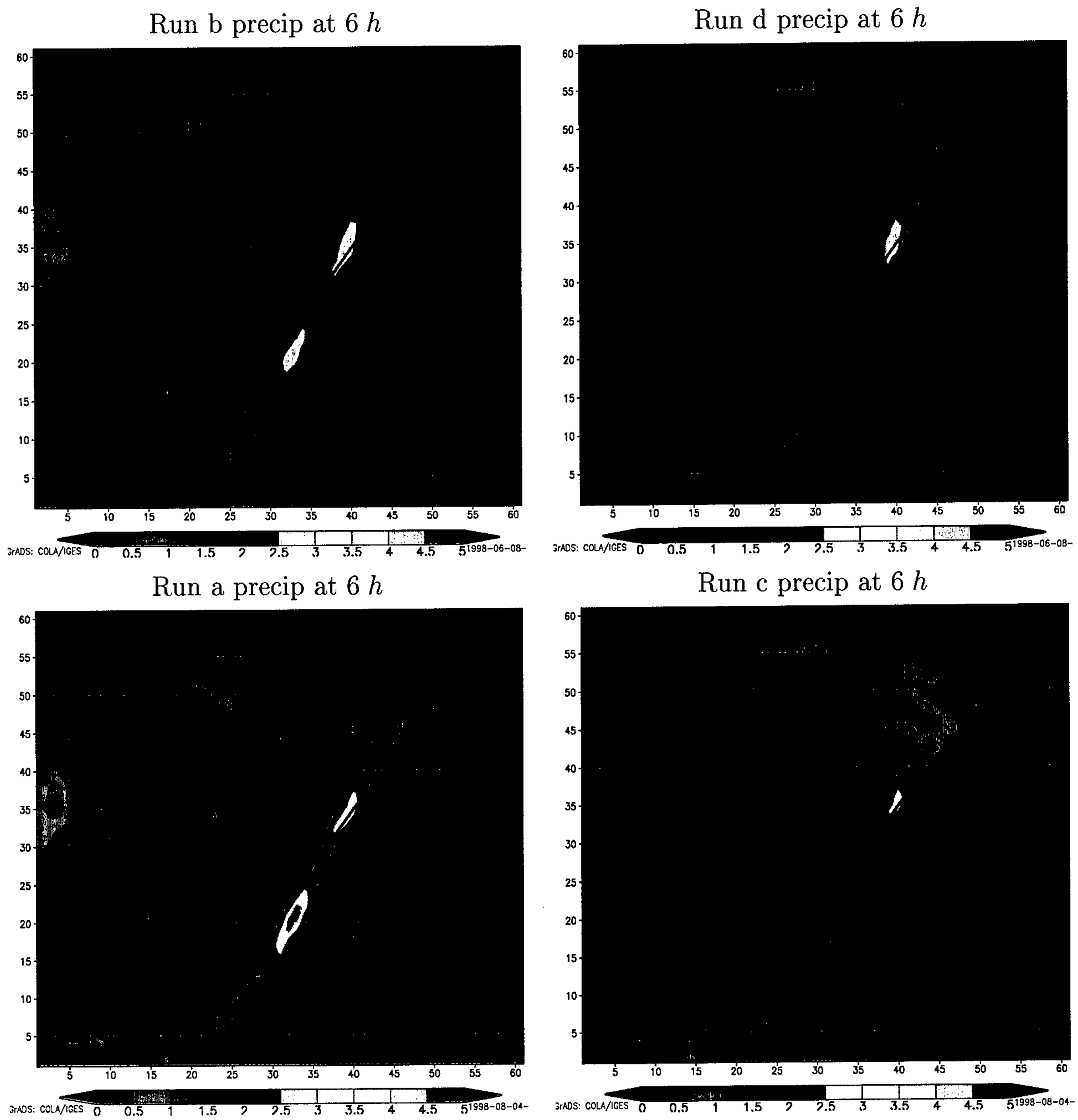

Figure 8: Forecast 1 h accumulated precipitation valid at 18 UTC 19 March 1979. Shown are the nominal (top row) and nodata (bottom row) forecasts, without (left column) and with (right column) adjustments. The straight line indicates the position of the surface front in the first guess.

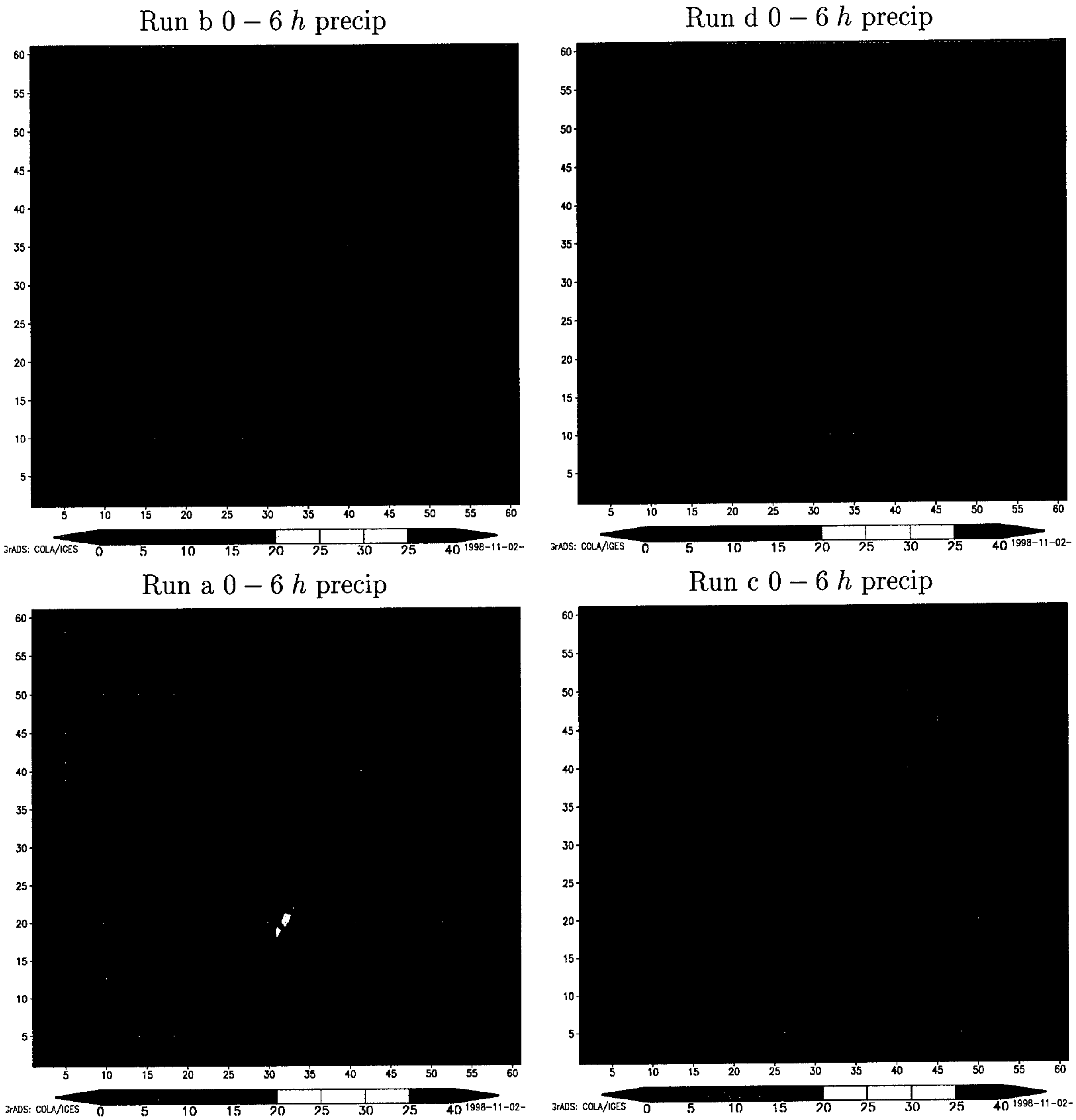

Figure 9: Forecast 6 h accumulated precipitation from 12 UTC to 18 UTC 19 March 1979. Shown are the nominal (top row) and nodata (bottom row) forecasts, without (left column) and with (right column) adjustments. The straight line indicates the position of the surface front in the first guess.

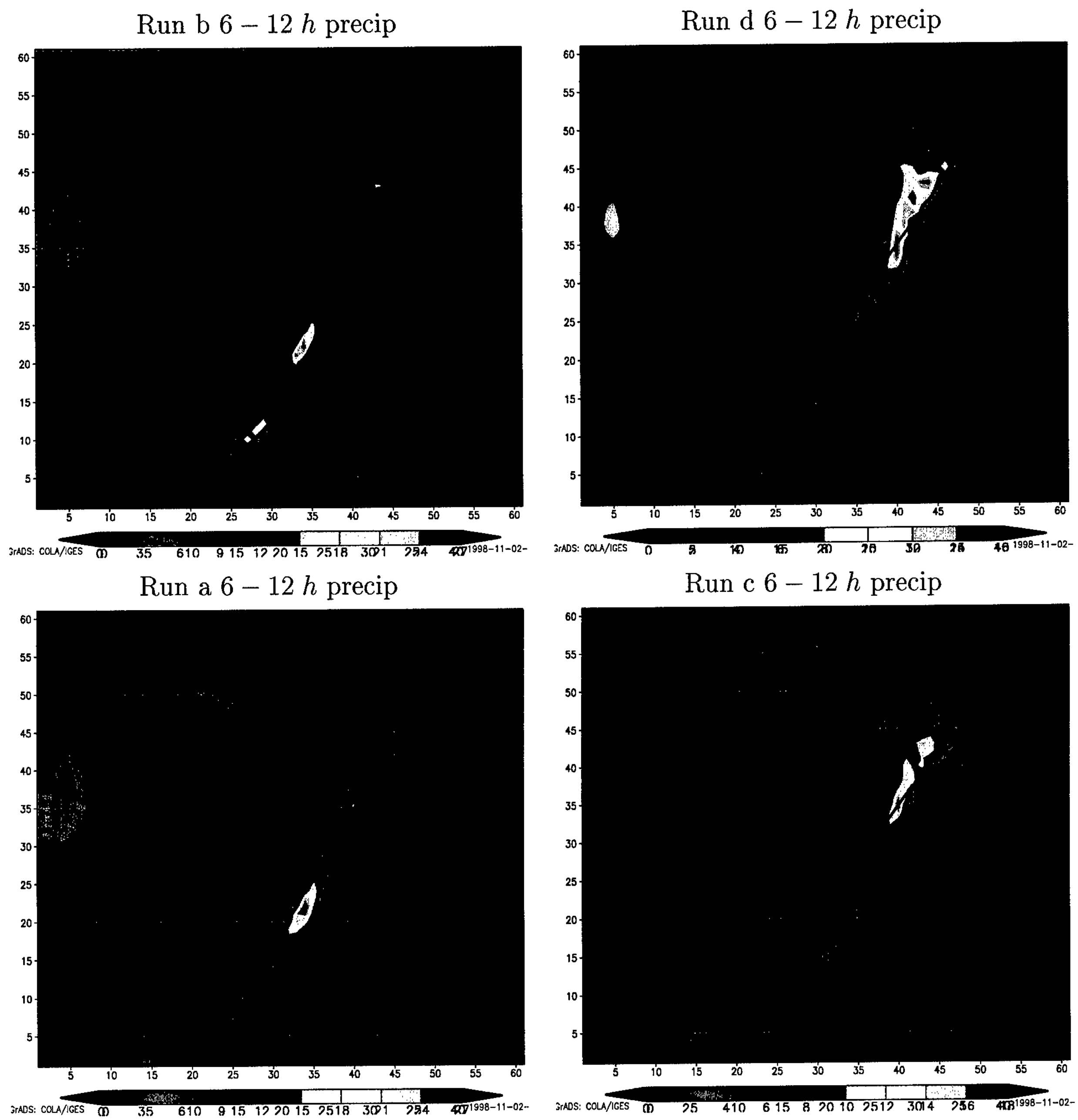

Figure 10: Forecast 6 h accumulated precipitation from 18 UTC 19 March to 00 UTC 20 March 1979. Shown are the nominal (top row) and nodata (bottom row) forecasts, without (left column) and with (right column) adjustments. The straight line indicates the position of the surface front in the first guess.

Statistic	Run a	Run b	Run c	Run d	Run e
bias	1.63	2.08	2.30	2.50	2.51
rms	4.00	3.89	3.36	3.68	3.71
sd	3.65	3.29	2.46	2.71	2.74

Table 3: Verification statistics for 12 h forecasts of IWV against SSM/I observations. Shown are the mean error (bias), root mean square (rms), and standard deviation (sd), based on a sample of 8697 observations.

Statistic	Run a	Run b	Run c	Run d
bias	-0.11	-0.14	-0.23	-0.22
rms	1.12	1.11	1.20	1.21
sd	1.12	1.10	1.18	1.19

Table 4: Verification statistics for 1 h precipitation rates at 3 h against SSM/I observations for 19 March 1997. Shown are the mean error (bias), root mean square (rms), and standard deviation (sd), based on a sample size of 6285 observations.

5.2 13-14 February 1998

5.2.1 Case Description

A baroclinic wave had developed on the cold front of a mature mid-Pacific cyclone at the valid time of the first guess fields, 0000 UTC 14 February 1998. A closed 500 hPa circulation was collocated with its associated deep surface low; both features slowly weakened and drifted east-northeastward through the forecast period. An elongated area of high pressure was positioned far to the south of the cyclonic system.

A tongue of moist air was positioned just ahead of the surface cold front, while to the northeast, strong low-level winds were advecting heat and moisture ahead of a pronounced warm frontal trough. This resulted in abundant precipitation over the northwestern United States early in the forecast period.

5.2.2 First Guess Adjustment and analysis and forecast impacts

The first guess forecast of IWV for this case (Figure 12) shows a moisture tongue associated with a frontal system extending to the eastnortheast from the western edge of the domain. SSM/I observations cover the eastern part of this moist tongue (Figure 11), and indicate that the tongue is too far north, and too moist. Because data are only available over part of the domain, the adjustments are essentially restricted to the eastern part of the front. The differences between the adjusted and control runs are signifcantly modified by the analysis step in this case (Figure 13): moisture values are reduced in both runs, leading to much smaller differences in magnitude, although the position of the moist tongue is still further south in the adjusted run. After 12 hours into the forecast, however, the position of the moist tongue is no longer different, but there are slight differences in magnitude. Verification of the 12 h forecast IWV fields against SSM/I observations (Table 5) shows a small, but positive impact. The change is smaller than the estimated IWV measurement errors, however, as was the case for the nominal runs for the 19 March 1997 case.

The effect of the first guess adjustments on the dynamic fields is shown in Figure 14, which shows the 1000 and 500 hPa height fields. The effect of the southward displacements along the center of the moist tongue is evident at both levels. After the analysis, however, the differences are much smaller (Figure 15). At 1000 hPa, the control run analysis was brought into closer agreement with the adjusted first guess (and analysis), whereas at 500 hPa the reverse was true. After the first 12 hours of the forecast, the initial differences are no longer discernible (they actually reversed in sign in part of the domain).

In this case, there was little or no precipitation in the area affected by the adjustments. Most of the precipitation occurred along the wave in the frontal system well to the northeast. Therefore, there are no discernible differences in precipitation initially (Figure 16), and only at 6 hours have differences between the two runs developed along the southern edge of the main area of precipitation. The plots of 6-hourly precipitation (Figure 17) show that this is the main area of differences in both the first and second 6 h period.

Comparison of 1-hourly precipitation rates against instantaneous precipitation rates ob-

served by SSM/I (Table 6) show a neutral to slightly negative impact of the adjustment, which are all within the measurement errors of the precipiation observations.

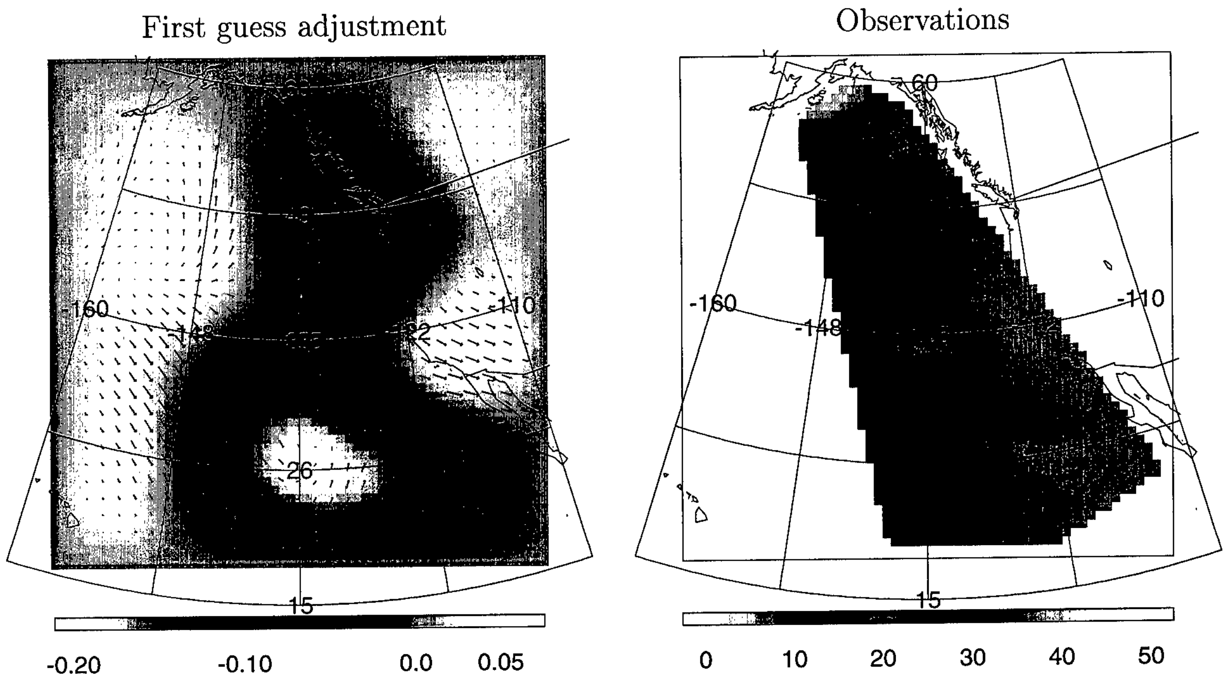

Figure 11: FCA for 00 UTC 14 February 1998. The SSM/I observations are shown in the right panel; the adjustment amplification factors and displacement vectors in the left panel.

Statistic	Control	Adjusted
bias	2.51	2.28
rms	5.66	5.23
sd	5.08	4.71

Table 5: Verification statistics for 12 h forecasts of IWV against SSM/I observations. Shown are the mean error (bias), root mean square (rms), and standard deviation (sd), based on a sample of 6901 observations.

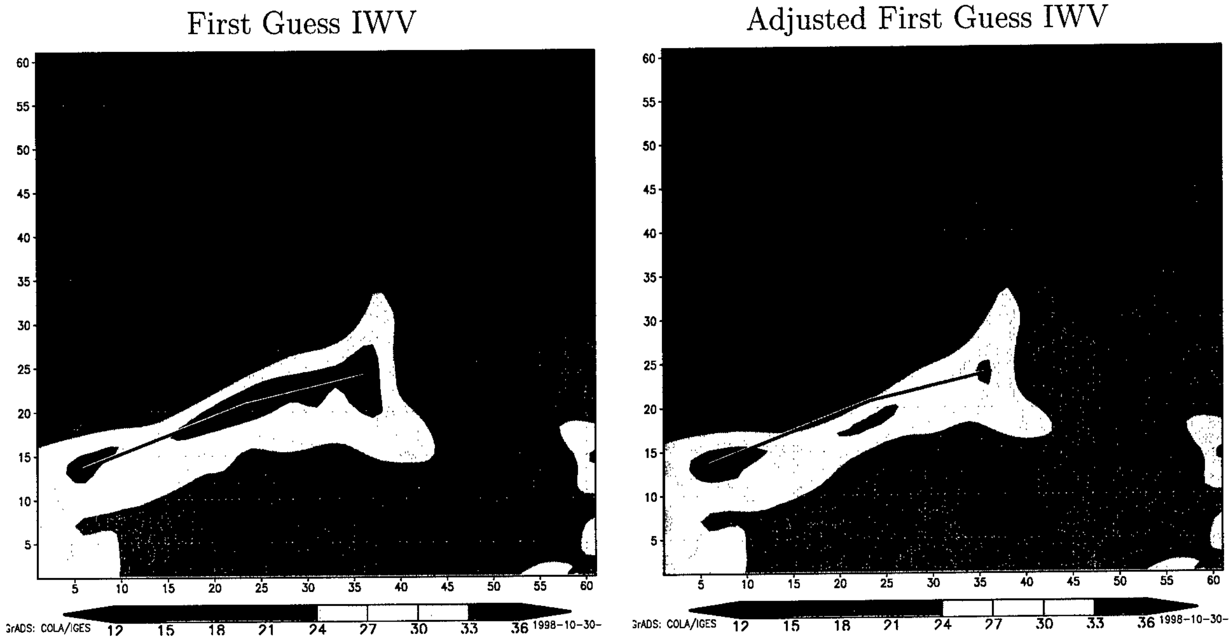

Figure 12: First guess IWV fields for 00 UTC 14 February 1998. Shown are the control and adjusted first guess fields integrated water vapor (IWV, in $kg\,m^{-2}$). The straight lines indicate the approximate position of the maximum IWV values in the control run first guess.

Statistic	3 h		4 h		6 h	
	Control	Adjusted	Control	Adjusted	Control	Adjusted
bias	-0.06	-0.05	-0.04	-0.04	0.00	0.00
rms	0.70	0.69	0.62	0.63	0.44	0.46
sd	0.70	0.69	0.62	0.63	0.44	0.46

Table 6: Verification statistics for 1 h precipitation rates against SSM/I observations for 14 February 1998. Shown are the mean error (bias), root mean square (rms), and standard deviation (sd), based on sample sizes of 11,456 to 18,666 observations.

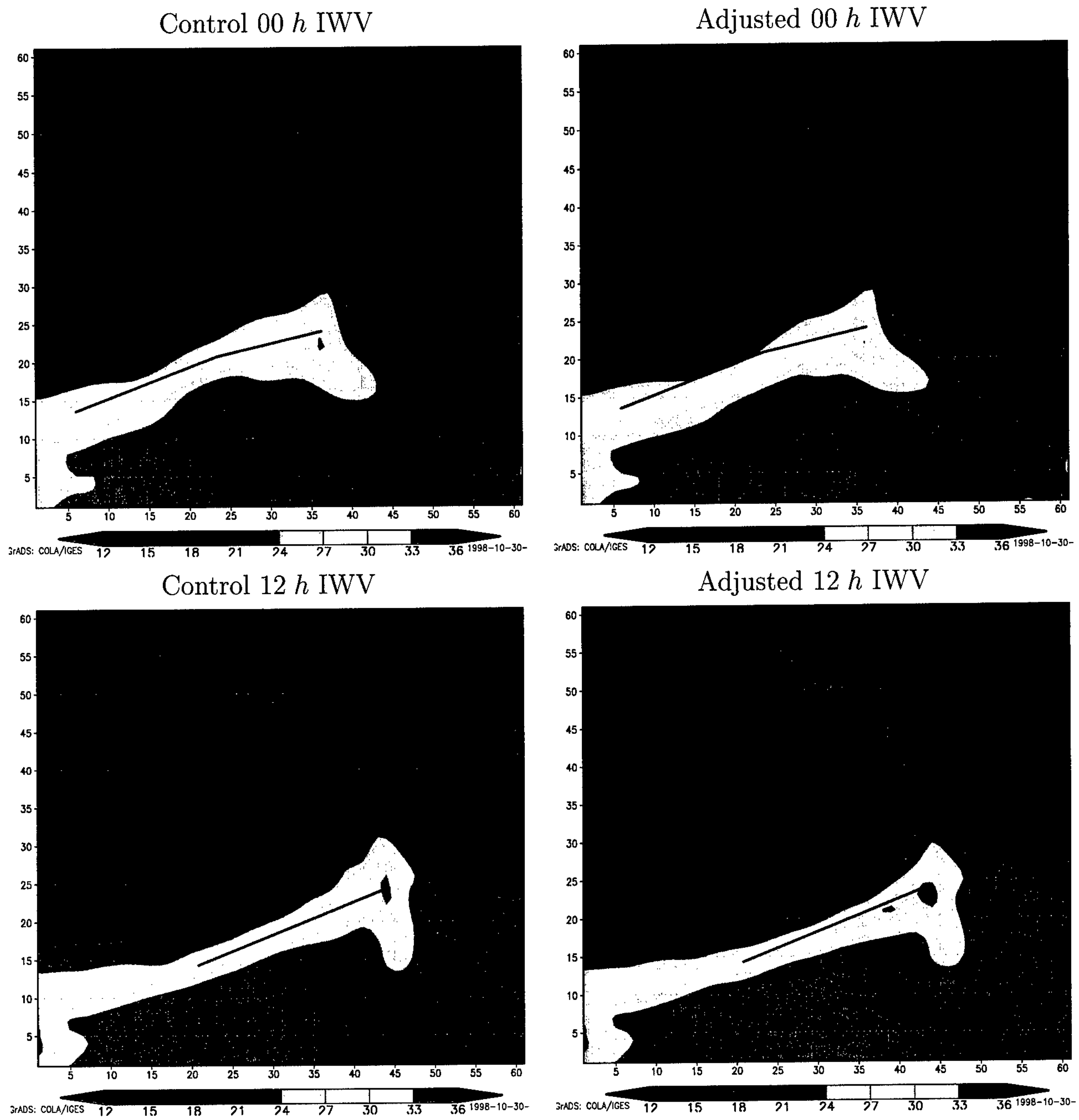

Figure 13: IWV fields for the analysis at 00 UTC 14 February (top row) and the 12 *h* forecast valid 12 UTC 14 February 1998 (bottom row), for the control and adjusted runs. The straight lines indicate the approximate position of the maximum IWV values in the control run first guess and 12 *h* forecast, respectively.

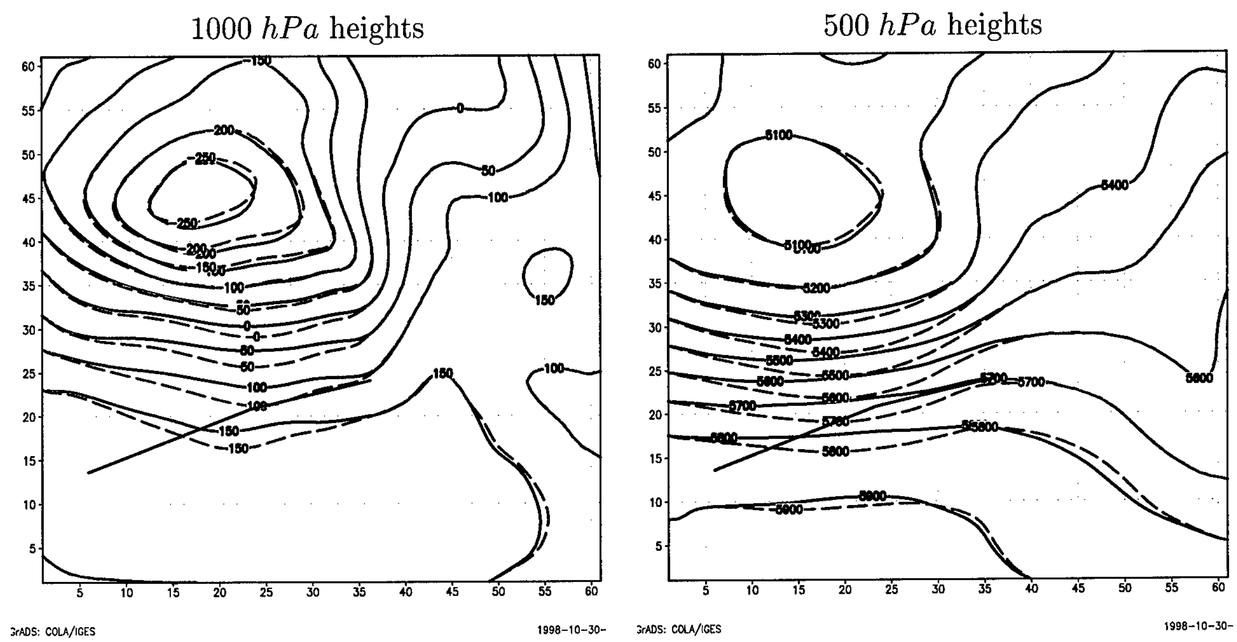

Figure 14: First guess 1000 and 500 hPa height fields for 00 UTC 14 February 1998. Original first guess is shown as solid contours, adjusted as dashed. The straight lines indicate the approximate position of the maximum IWV values in the control run first guess.

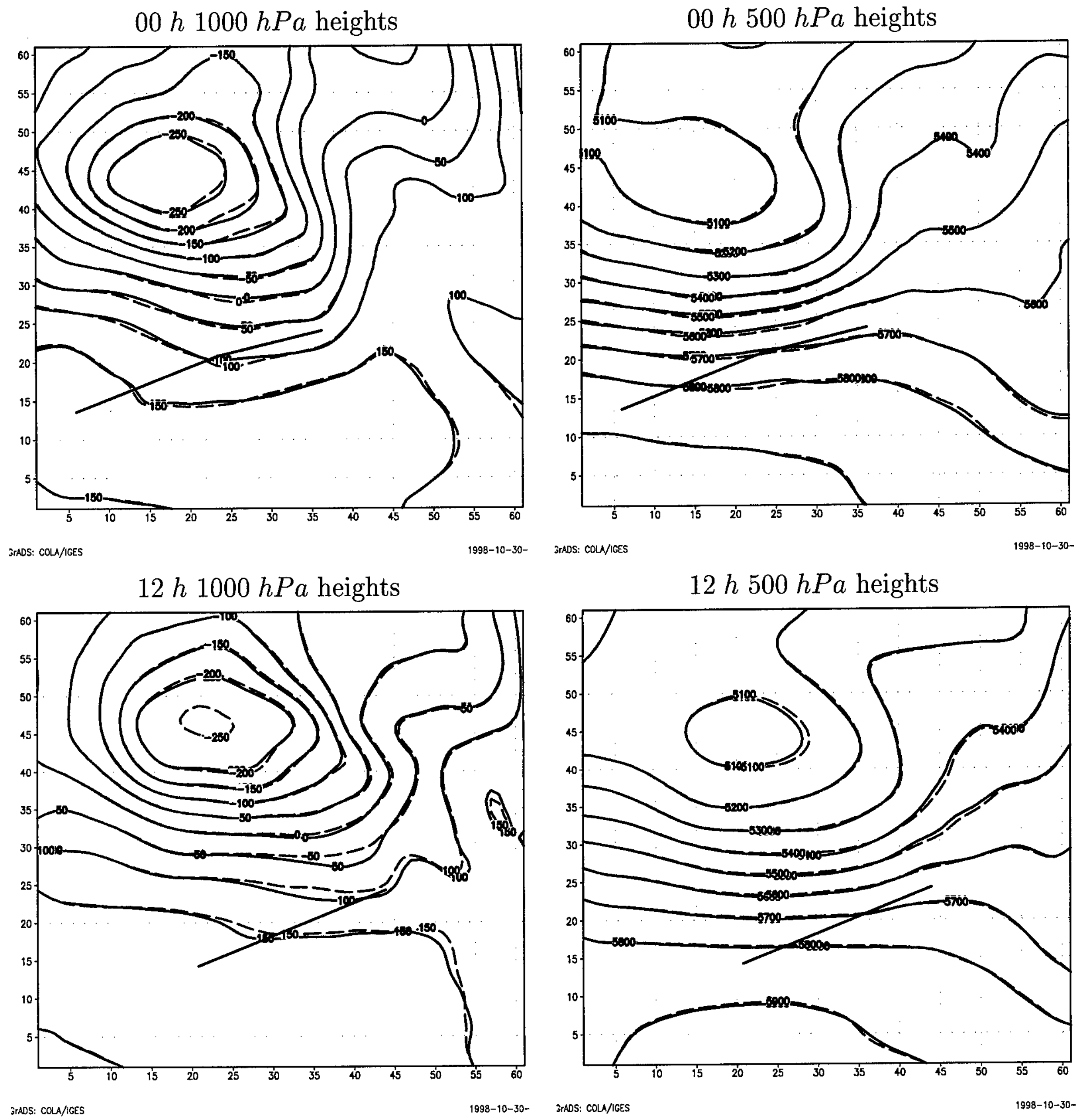

Figure 15: Height fields for the analysis at 00 UTC 14 February (top row) and the 12 h forecast valid 12 UTC 14 February 1998 (bottom row), for the control and adjusted runs. Control run results are shown as solid contours, adjusted as dashed. The straight lines indicate the approximate position of the maximum IWV values in the control run first guess and 12 h forecast, respectively.

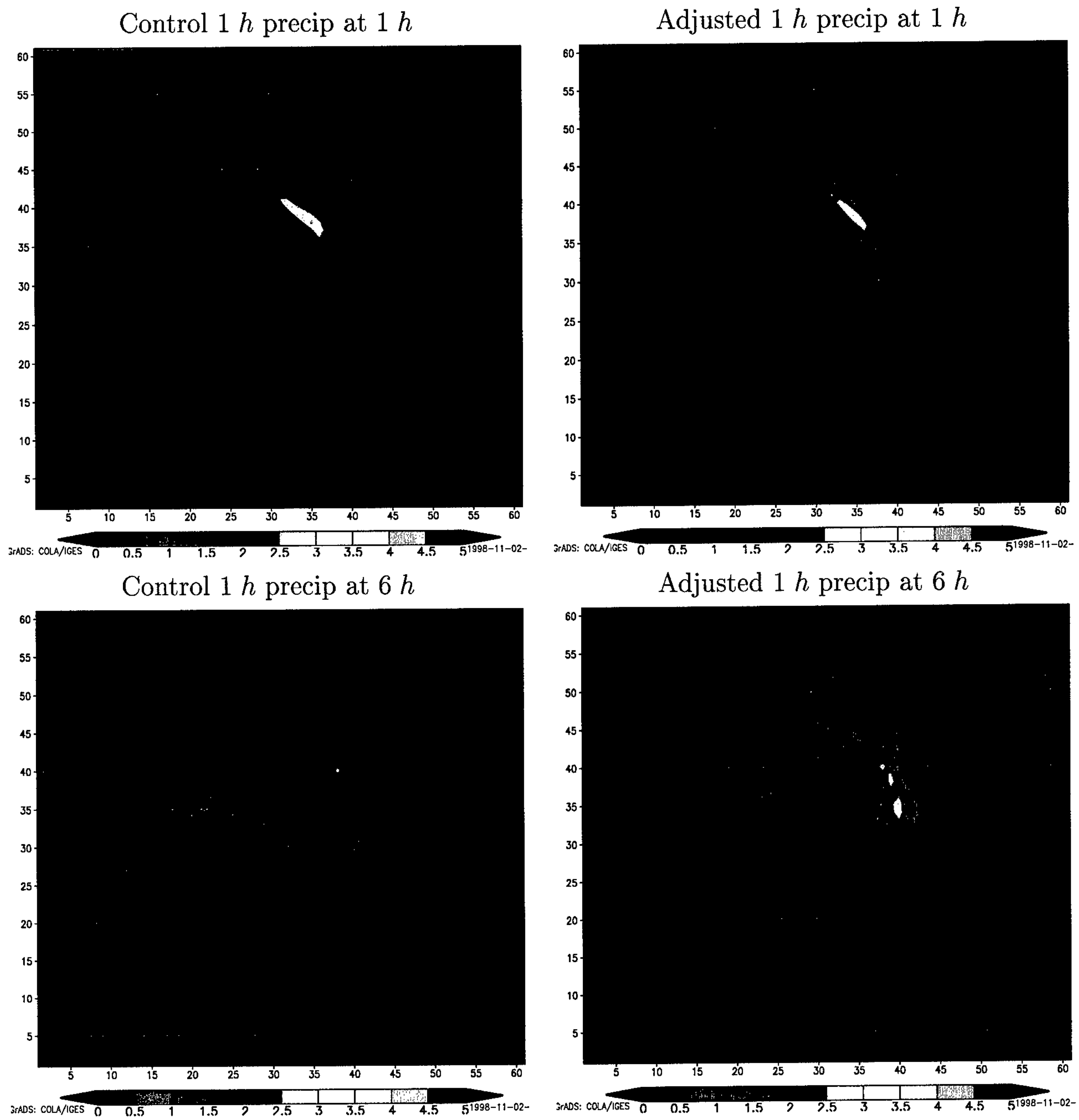

Figure 16: Forecast 1 h accumulated precipitation for 14 February 1998. Shown are the values valid 01 UTC (top tow) and 06 UTC (bottom row), without (left column) and with (right column) adjustments. The straight lines indicate the approximate position of the maximum IWV values in the control run first guess and 12 h forecast.

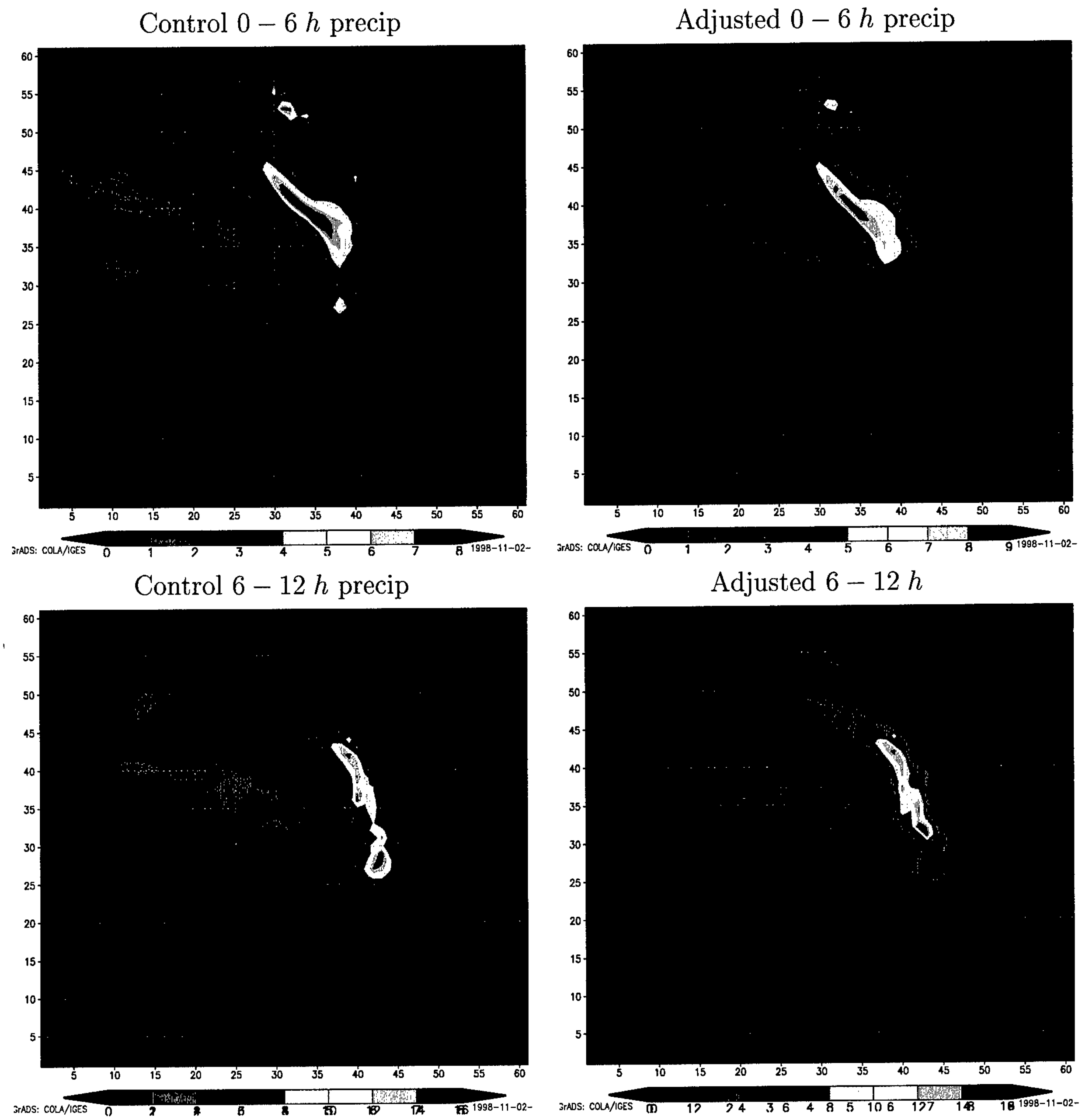

Figure 17: Forecast 6 h accumulated precipitation for 14 February 1998. Shown are the values from 00 UTC to 06 UTC (top tow), and 06 UTC to 12 UTC 14 February 1998 (bottom row), without (left column) and with (right column) adjustments. The straight lines indicate the approximate position of the maximum IWV values in the control run first guess and 12 h forecast.

5.3 15 January 1998

5.3.1 Case Description

A deep and mature surface low (central pressure below 965 hPa) was positioned well off the Oregon coast at the valid time of the first guess fields, 1200 UTC 15 January 1998. At 500 hPa, the deep surface low was represented by a shortwave trough moving northeastward around a closed low positioned well to the northwest. Over the next 12 h, the 500 hPa closed low remained almost stationary, while the upper-level representation of the slowly deepening surface low moved northeastward and similarly intensified. The warm frontal trough extending southeast from the surface low also became more pronounced as did the downstream deep-layer ridge.

Abundant moisture (IWV ¿ 35 mm) in the tropical air to the south of the system was being transported northeastward by the strong low-level wind field between the low and a large anticyclone to its southeast . Although the center of the surface low moved generally northeastward, remaining well off-shore through the forecast period, warm frontal precipitation occurred over the northwestern United States.

5.3.2 First Guess Adjustment and analysis and forecast impacts

The first guess in this case included a wavelike disturbance of the main moisture tongue, associated with a surface low pressure system. The adjustments based on the available SSM/I IWV data lead to a reduction of IWV values near the center of the low (Figure 18), and a general southeastward displacement of the features in the forecast field (Figure 19). However, the vorticity maximum associated with the low is also weakened by the adjustments. After the analysis step, the IWV fields are reduced in the control run, but increased in some areas in the adjusted run, leading to a reversal of the differences near the center of the low (Figure 20), and generally only small differences in the position of moist tongue. After 12 hours, there are few visible differences between the two runs, except for an area of slightly higher values in the adjusted run.

Comparison of the 12 h forecast against SSM/I IWV observations (Table 7) shows a slight positive impact in terms of mean square statistics, but a slight increase of the positive bias. These differences are smaller than the IWV measurement errors, however.

The vorticity fields are generally much noisier after the analysis step (Figure 21), and the clearly visible shift in the position of the first guess vorticity maximum is modified by structural changes in the vorticity features. After 12 hours, the main differences between the two runs are a different structure of the vorticity maximum, and slightly lower values along the warm front, with almost no differences in position.

The effects of the adjustments on the precipitation field (Figure 22) are minor. At the initial time, the main area of precipitation is moved and weakened in the same way as the associated vorticity field. However, after 6 hours, the precipitation has regained strength in the adjusted run, and there is a slight difference in position of the main warm frontal precipitation. The plots of 6-hourly precipitation (Figure 23) show that this trend continues

throughout the seond 6 h period.

Comparisons against SSM/I observations of precipitation (Table 8) are inconclusive (all the differences are smaller than the measurement errors of the precipitation observations).

Statistic	Control	Adjusted
bias	1.34	1.39
rms	4.33	4.20
sd	4.12	3.97

Table 7: Verification statistics for 12 h forecasts of IWV against SSM/I observations for 15 January 1998. Shown are the mean error (bias), root mean square (rms), and standard deviation (sd), based on a sample of 7149 observations.

Statistic	4 h		6 h		7 h	
	Control	Adjusted	Control	Adjusted	Control	Adjusted
bias	-0.02	-0.01	0.05	0.03	0.04	0.01
rms	0.64	0.67	0.61	0.60	0.74	0.75
sd	0.64	0.67	0.61	0.59	0.74	0.75

Table 8: Verification statistics for 1 h precipitation rates against SSM/I observations for 15 January 1998. Shown are the mean error (bias), root mean square (rms), and standard deviation (sd), based on sample sizes of 10,785 to 16,933 observations.

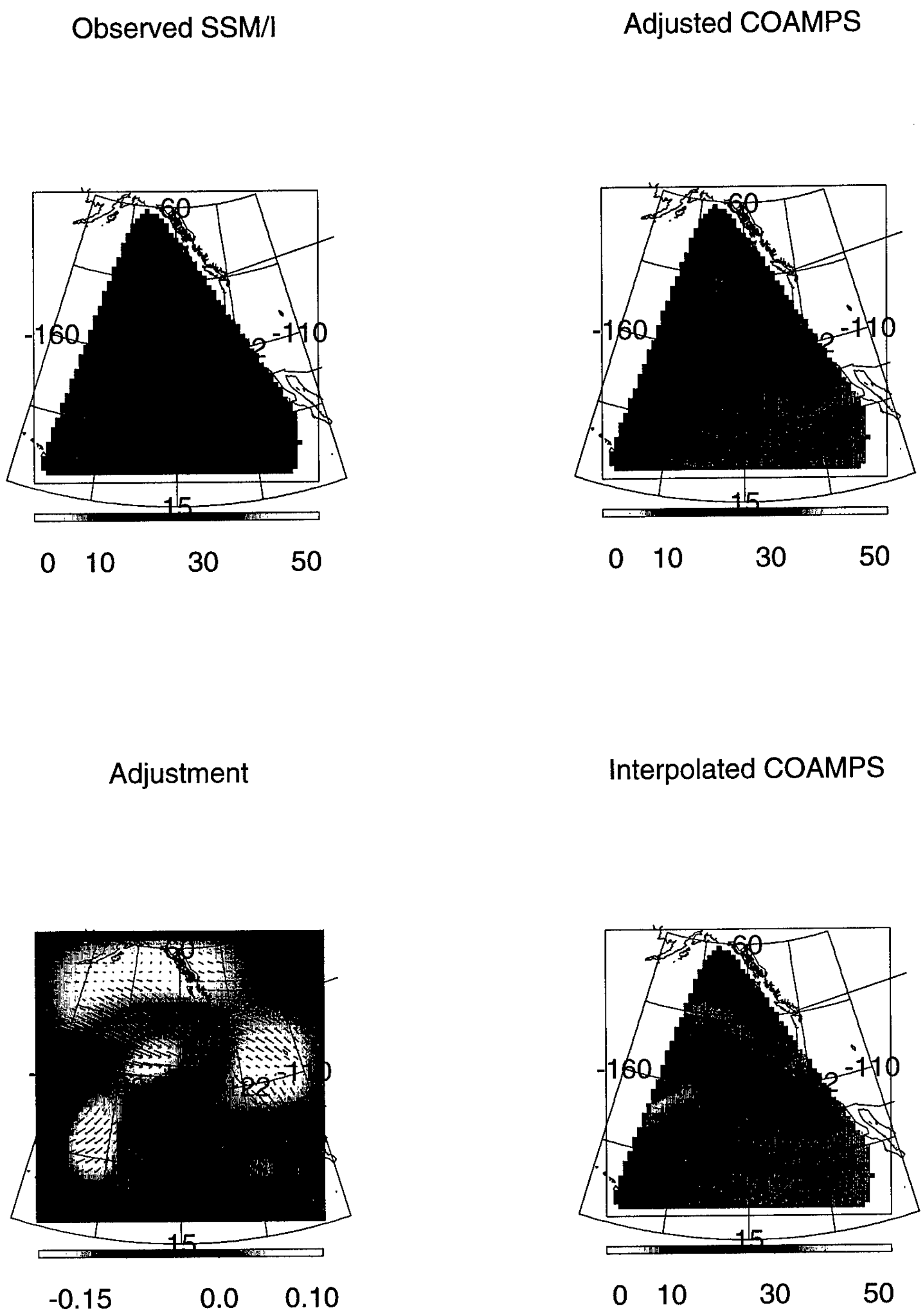

Figure 18: FCA for 12 UTC 15 January 1998. The SSM/I observations are shown in the top left panel; the adjusted first guess in the top right panel; the adjustment amplification factors and displacement vectors in the bottom left panel; and the original first guess integrated water vapor field in the bottom right panel.

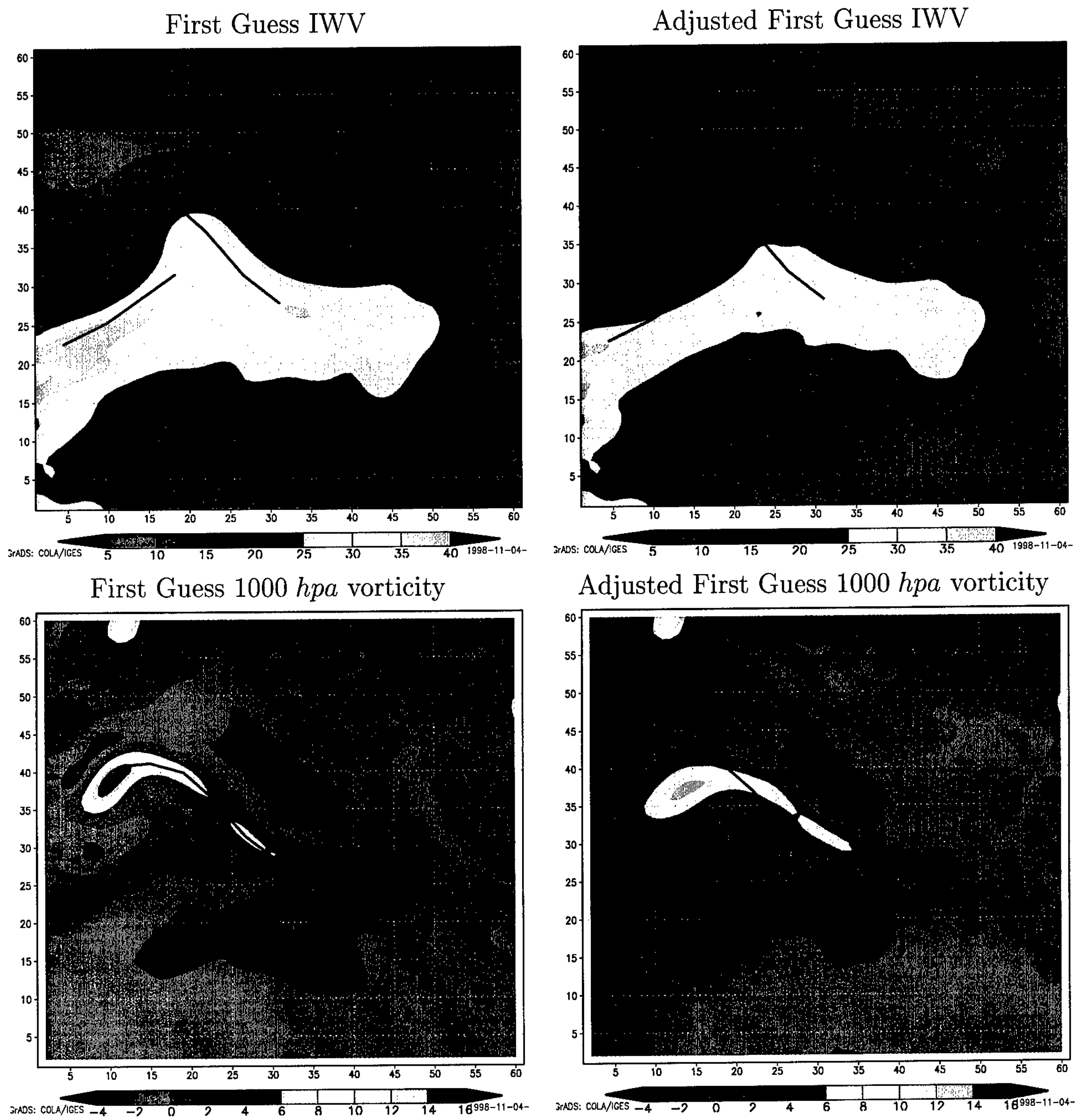

Figure 19: First guess fields for 12 UTC 15 January 1998. Shown are the control (left column) and adjusted (right column) first guess fields of integrated water vapor (top row, in $kg\,m^{-2}$) and 1000 hPa relative vorticity (bottom row, in $10^{-5}s^{-1}$). The straight lines indicate the position of the surface fronts in the control run (as indicated by the first guess 1000 hPa relative vorticity maximum).

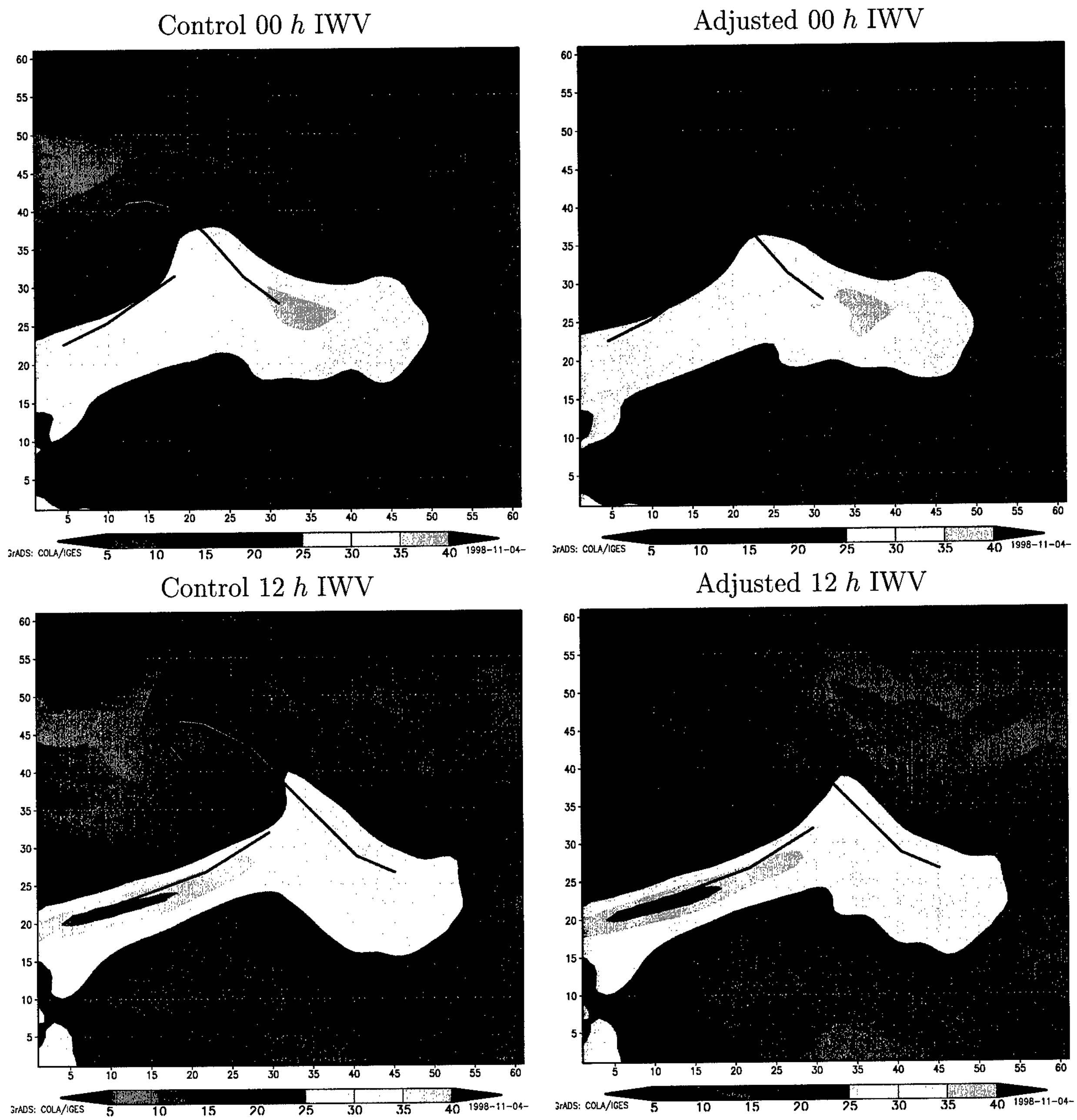

Figure 20: IWV fields for the analysis at 12 UTC 15 January 1998 (top row) and the 12 h forecast valid 00 UTC 16 January 1998 (bottom row), for the control and adjusted runs. The straight lines indicate the position of the surface fronts in the control run (as indicated by the first guess and 12 h forecast 1000 hPa relative vorticity maximum).

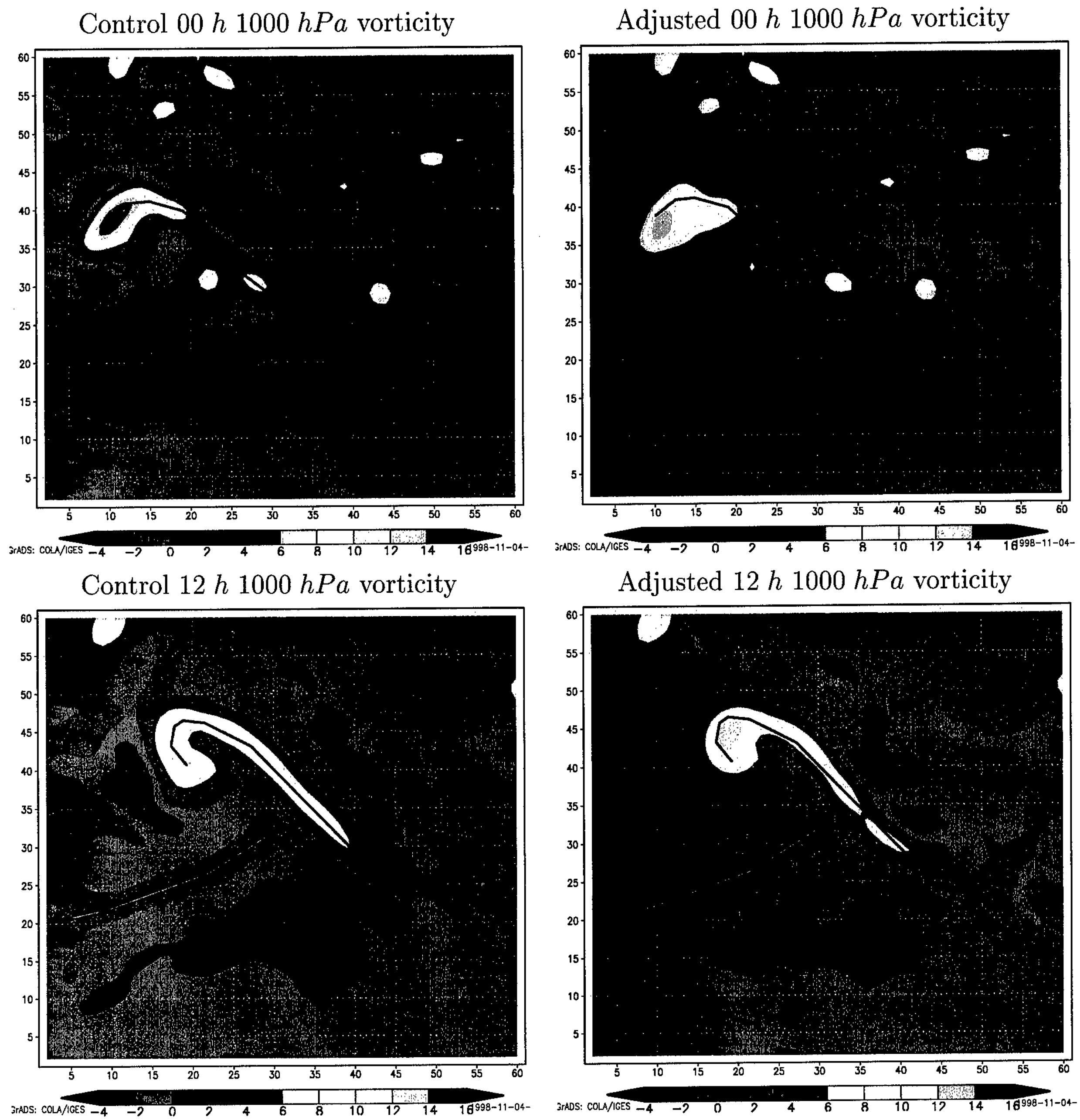

Figure 21: 1000 hPa vorticity fields for the analysis at 12 UTC 15 January 1998 (top row) and the 12 h forecast valid 00 UTC 16 January 1998 (bottom row), for the control and adjusted runs. The straight lines indicate the position of the surface fronts in the control run (as indicated by the first guess and 12 h forecast 1000 hPa relative vorticity maximum).

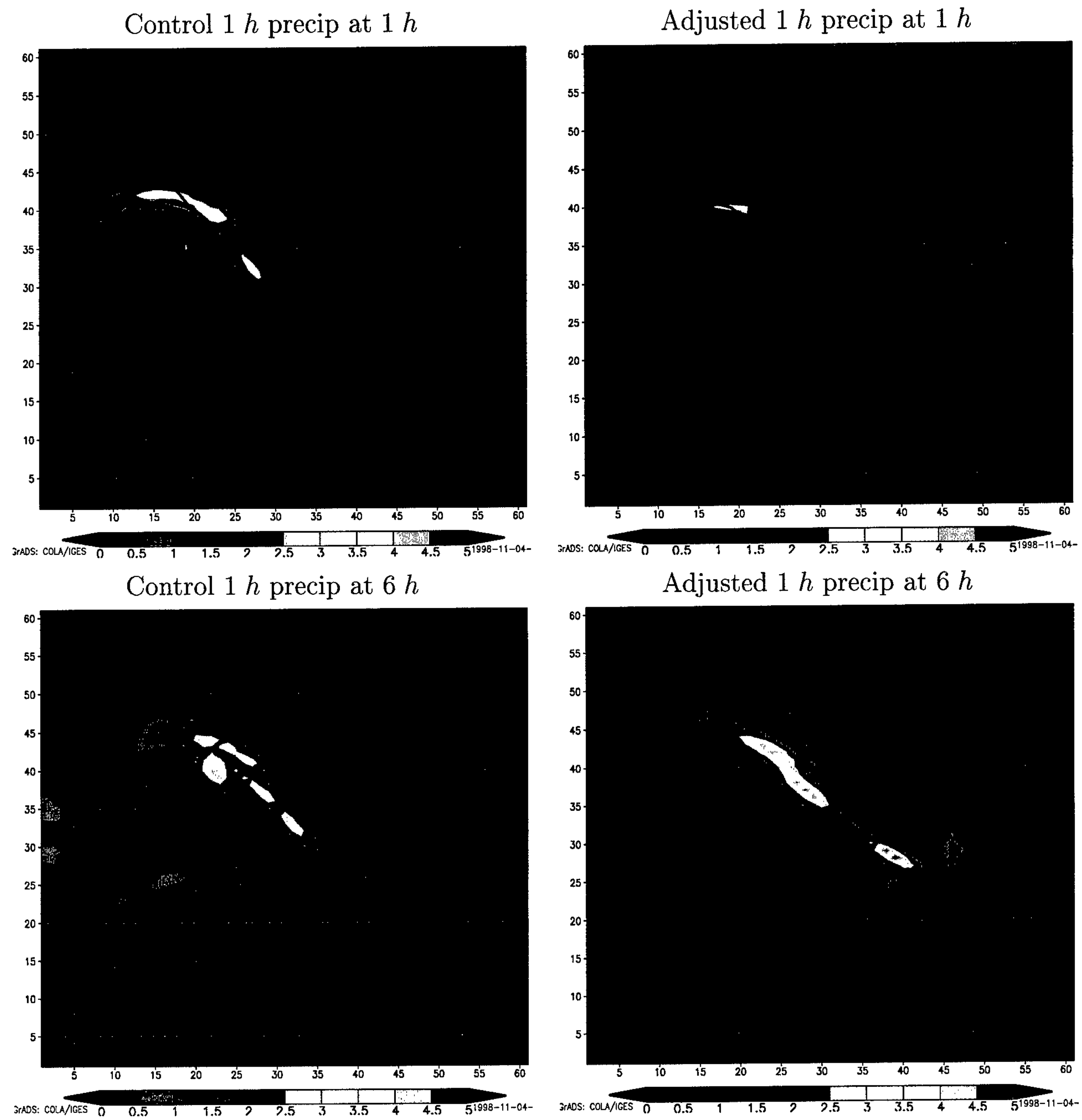

Figure 22: Forecast 1 h accumulated precipitation for 15 January 1998. Shown are the values at 13 UTC (top row) and 18 UTC 15 January 1998 (bottom row), without (left column) and with (right column) adjustments. The straight lines indicate the position of the surface fronts in the control run (as indicated by the first guess and 12 h forecast 1000 hPa relative vorticity maximum).

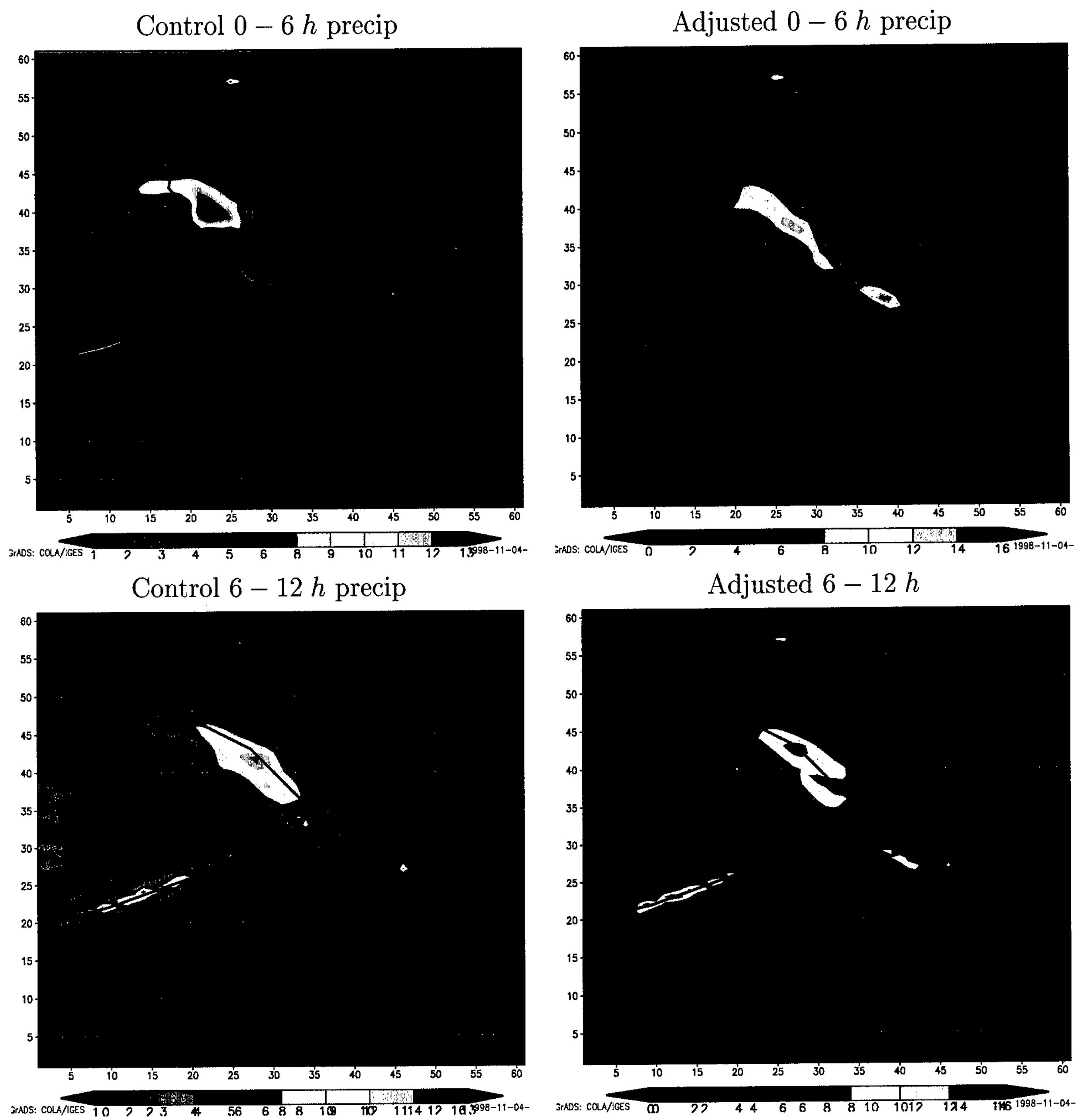

Figure 23: Forecast 6 h accumulated precipitation for 15 January 1998. Shown are the values valid from 12 to 18 UTC 15 January (top row) and 18 UTC 15 January to 00 UTC 16 January 1998 (bottom row), without (left column) and with (right column) adjustments. The straight lines indicate the position of the surface fronts in the control run (as indicated by the first guess and 12 h forecast 1000 hPa relative vorticity maximum).

6 Conclusions

The results indicate that the adjustments to the first guess forecasts are successful in two regards: they do not introduce spurious noise into the forecasts, and they lead to an improvement of the IWV forecasts. Verification of precipitation forecasts did not show a clear positive or negative effect. The results also indicate that the adjustments only partially survive the data analysis steps of the COAMPS data assimilation system, greatly diminishing its potential impact. More effective ways of initializing the COAMPS model with the adjusted model fields are required, since the impact diminishes during the first 12 hours of the forecast.

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